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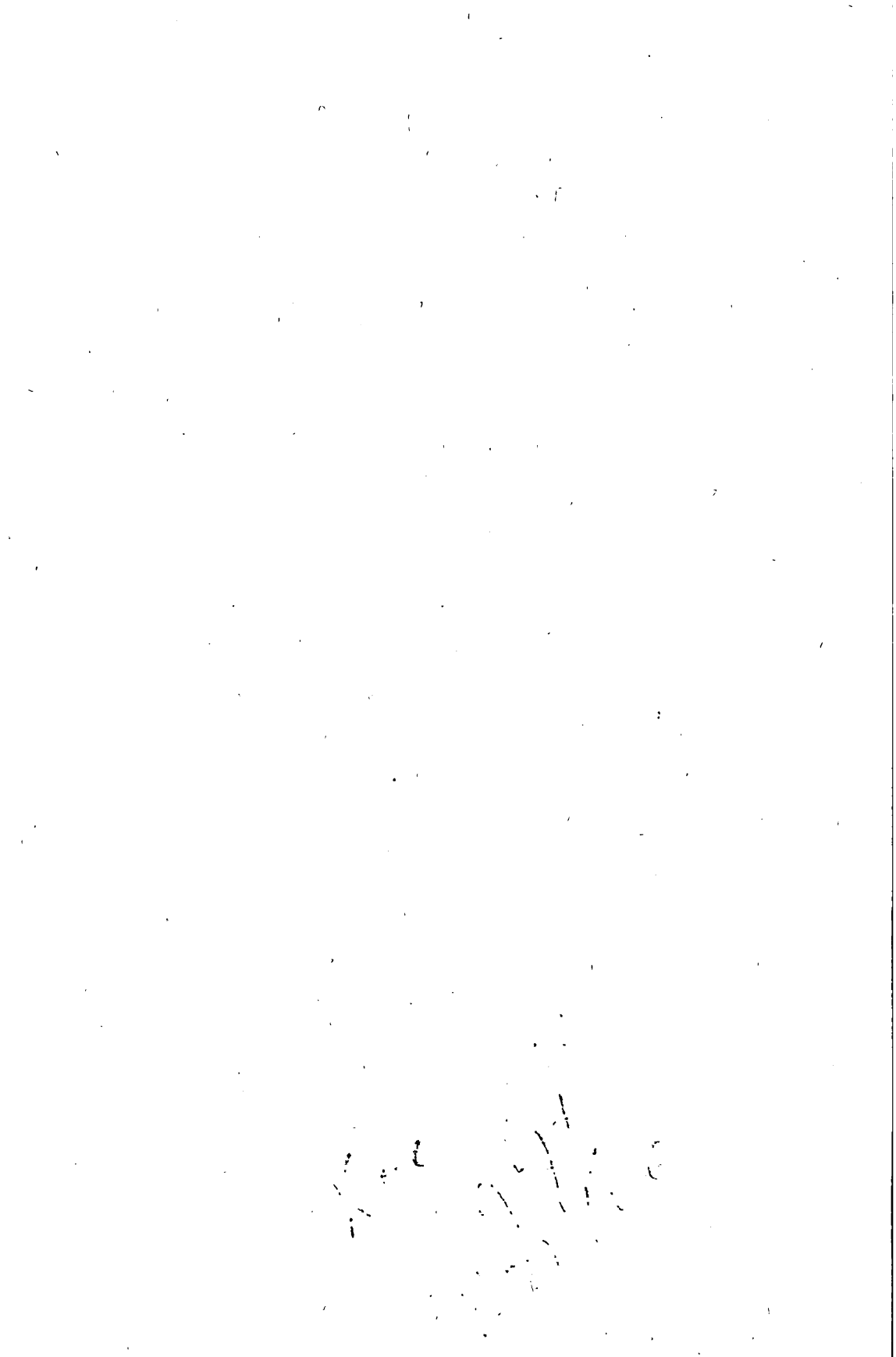
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TECHNICAL MANUAL

ELECTRICAL FUNDAMENTALS

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1941

CHANGES No. 1

WAR DEPARTMENT,
WASHINGTON, December 29, 1941.

TM 1–455, January 27, 1941, is changed as follows:

5. Representing a field of force.

* * * * * * *

b. Figure 3 shows the dielectric field about isolated charges represented by lines of force.

* * * * * * *

① Dielectric field about a **positive** charge.

② Dielectric field about a **negative** charge (electron).

FIGURE 3.

* * * * * * *

[A. G. 062.11 (11–7–41.)] (C 1, Dec. 29, 1941.)

34. Parallel circuit rules and formulas.

* * * * * * *

d. There are several methods * * * If this is substituted in the above formula and the E's are eliminated since they are all equal in a parallel circuit, the well-known formula for the total resistance of a parallel circuit is obtained:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{etc.}}$$

In other words * * * of the individual resistances.

* * * * * * *

[A. G. 062.11 (11–7–41.)] (C 1, Dec. 29, 1941.)

86. Capacitive reactance.—As was the case with inductance * * * and the frequency. The formula for capacitive reactance is:

$$X_c = \frac{1}{2\pi fC}$$

It could also be written $X_c = \frac{1}{6.28fC}$. In using this formula to get X_c in ohms, f must be in cycles per second and C in farads. Notice that * * * will be the opposition or capacitive reactance.

[A. G. 062.11 (11–7–41.)] (C 1, Dec. 29, 1941.)

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:

E. S. ADAMS,
Major General,
The Adjutant General.

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U. S. GOVERNMENT PRINTING OFFICE: 1942

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TECHNICAL MANUAL
No. 1-455

WAR DEPARTMENT,
WASHINGTON, *January 27, 1941.*

ELECTRICAL FUNDAMENTALS

Prepared under direction of the Chief of the Air Corps

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SECTION I

ELECTRICAL ENERGY

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1. General.—*a.* Material things can be classified under the general categories of matter and energy. Matter can be defined as anything which occupies space and has weight. This will represent any tangible substance and can be measured in terms of either the weight or dimensions. On the other hand, energy is intangible. It can merely be represented by its effects on matter and can be defined as the capacity for doing work. Energy can take on various forms, such as mechanical energy, chemical energy, heat energy, and electrical energy. Any of these forms can be transferred from one form to the other. In a limited system there has never been observed a loss or gain in the total energy. This is known as the law of conservation of energy. Another way to state this law is to say that energy can neither be created nor destroyed.

b. In the study of electricity it is convenient to approach it from an energy viewpoint many times, and the law of conservation of energy should always be borne in mind. Electrical energy can be divided into three general classifications—static electricity, dynamic or current electricity, and magnetism. Each can be converted into the others. As was stated before, energy is measured by its effects on matter. These effects are usually such as to produce motion. From this viewpoint, the unit for energy is equal to the force necessary to produce the motion multiplied by the distance the object is moved—hence, the expression "foot-pounds." The unit of electrical energy, although it could be expressed in foot-pounds, is expressed in "joules." The joule will be used to arrive at other fundamental electrical units.

2. Electrons.—*a.* For our purpose in the study of electricity, it is important to understand the subdivisions into which matter can be divided. Consider water as an example. Water is matter, for certainly it occupies space and has weight. Depending on the temperature, it may exist as a liquid, a solid, or a gas, under the common names of water, ice, or steam. Regardless of the temperature, it will still have the same composition. Starting with a bucket of water, if half is poured out and half is retained, and this process continued, eventually a quantity of water will be obtained which cannot be further divided without it ceasing to be water. This amount is a molecule of water. If this molecule of water is divided, instead of having two parts of water, there will be one part of oxygen and two parts of hydrogen (H_2O). Hydrogen and oxygen are both gases at normal temperature and pressure. If a quantity of hydrogen is repeatedly subdivided, a molecule of hydrogen will finally be obtained. Likewise if a quantity of oxygen is repeatedly

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subdivided, a molecule of oxygen will finally be obtained. In this case, unlike water, the molecule can be further subdivided and the substance still remains hydrogen or oxygen as the case may be.

b. When a molecule of hydrogen or oxygen is subdivided, there will be two atoms of hydrogen or two atoms of oxygen. From the above considerations, it is concluded that the molecule is a natural particle of matter which is composed of two or more atoms. There is an exception to this statement, for in a few substances the molecule and the atom are identical. The oxygen molecule has two atoms of oxygen; the hydrogen molecule has two atoms of hydrogen; and the water molecule has two atoms of hydrogen along with one atom of oxygen.

c. Matter which is composed of only one kind of atom is an element. There are 92 different elements. Oxygen, hydrogen, iron, carbon, and copper are a few examples of elements. Matter which is composed of more than one kind of atom is called a compound. Most of the substances in the world are compounds. Water, wool, cloth, salt, and sugar are a few examples of compounds. For a long time it was thought that the atom was the smallest subdivision of matter. In recent years a theory has been advanced which explains much of the observed electrical phenomena. According to this theory, the atom is not the smallest subdivision of matter. Each of the 92 different kinds of atoms are composed of electrons and protons. In other words, all matter is composed of just two things, electrons and protons; furthermore, the electrons and protons from one element are identical to those from any of the other elements. The reason that there are 92 different kinds of elements is not that they are composed of different constituents, but that the arrangement of the electrons and protons is different for the different elements. The electron is the smallest negative charge of electricity which is known of at the present time. The proton is a small, natural, positive charge of electricity. Although this is still considered to be theory, scientists have measured the mass and size of the electron and proton. Also, they know how much charge each possesses. The electron and proton each have the same charge, although the mass of the proton is many times that of the electron. Some scientists think that the proton is composed of a positron and a neutron, the positron having the same mass and charge as the electron and the neutron having no electrical charge. The electrons and protons of the atoms are arranged in similar manner to our solar system. The protons form a positive nucleus around which the electrons rotate. In our solar system the Sun would represent the nucleus, and the Earth, Mars, Venus, and the other planets would represent the electrons. The hydrogen atom has the simplest structure. It has one proton for the

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nucleus and one electron rotating about it. Other atoms are more complicated with many protons in the nucleus and a like number of electrons rotating at various distances from the center and in various directions.

d. Figure 1 shows several of these atom structures. Figure 1① shows the simplest atom; ② and ③ are atoms with a slightly more complex structure; and ④ is supposed to represent a carbon atom. Note that in figure 1③ and ④ there are a few electrons trapped inside the nucleus. These might be called nuclear electrons.

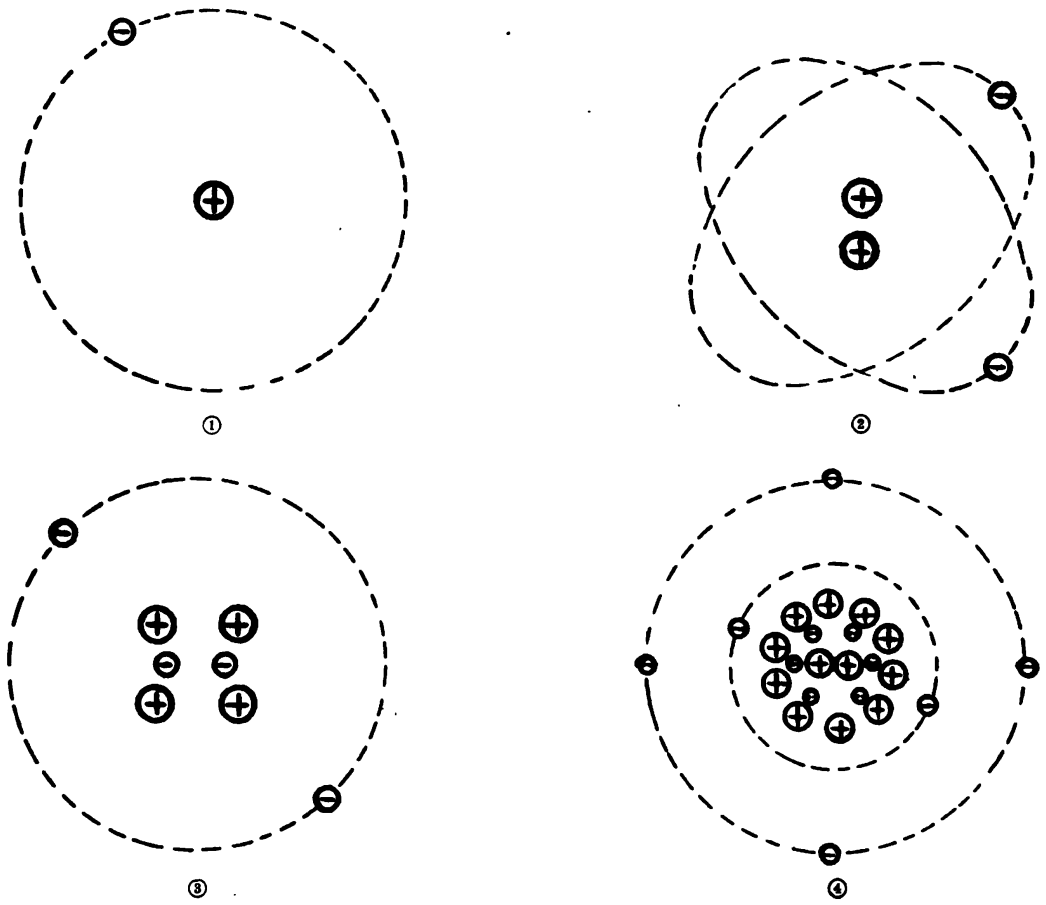


FIGURE 1.—Atomic structures.

e. The different atomic structures cause the 92 elements to possess different properties. Some are hard while others are soft; some are brittle and others are elastic; some will burn and some will not. These properties and other physical and chemical properties, as well as the electrical properties of matter, are determined by the structure of their atoms—the way atoms go together to make molecules and the arrangement of the molecules.

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f. There are many important electrical properties but only two will be considered here. They have the same relation to each other as the physical properties, hardness and softness. These two electrical properties are called conductance and resistance. Conductance is the ability of a substance to conduct electricity, that is, allow electricity to flow through it. Resistance is the measure of the ability of a substance to oppose the flow of electricity through it. As would be expected, it is not the positive nucleus or protons that flow, as they are down inside the atom and also are much heavier (have more mass) than the electrons. In addition, many of the electrons are rotating so close to the nucleus that they never leave the atom. These electrons are called planetary electrons. Other electrons are rotating at relatively greater distances from the nucleus, probably in elliptical orbits such that the orbits from one atom overlap the orbits of the next atom. These electrons are not attached tightly

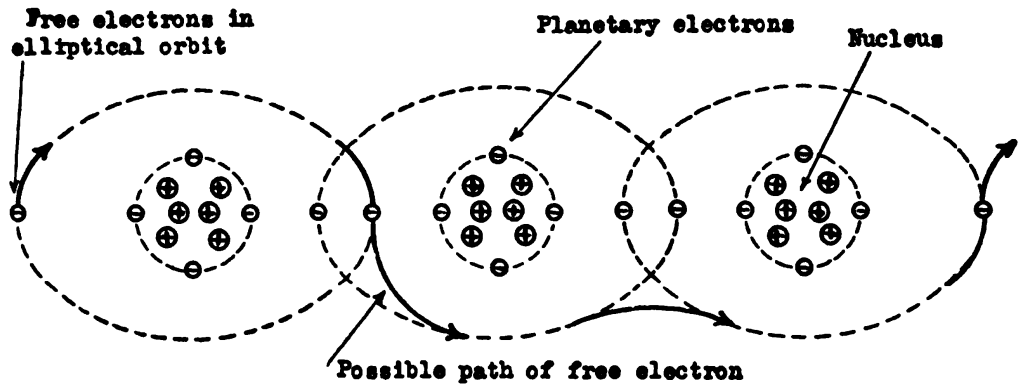


FIGURE 2.

to any one atom and are termed free electrons. Figure 2 shows how these free electrons may travel from atom to atom. Note that the method does not attempt to simulate any particular material or show how any actual free electron does travel, but merely shows how it is possible for the free electrons to travel from atom to atom as chance or some force may dictate. The relative number of free electrons has a definite bearing on the conductance or resistance of the material. The substance with the greater number of free electrons will be the better conductor and have the higher conductance. A substance with only a few free electrons has a high resistance. Substances with practically no free electrons are called insulators or nonconductors.

3. Static electricity.—*a.* Static electricity was originally considered to be electricity at rest. Now, since the electrons and protons have been considered as the ultimate charges of electricity, and it has

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been seen that in the atoms the electrons are in continual motion, it might be better to consider static electricity as being electricity associated with insulators or dielectrics. Lightning discharges and the crackling sounds in a radio receiver on a hot summer night are manifestations of static electricity.

b. Bodies can be charged with static electricity by various methods. A charged body merely means that the object has more or less than its normal number of electrons. In the uncharged state, each atom has an equal number of electrons and protons, so in order to charge a body, since the electrons are rotating outside the nucleus, it is merely necessary to remove some of these electrons in order to charge the body positively. In this case there will be an excess of protons, or positive charges, since some of the negative electrons have been removed. Now the question arises, "Where did these electrons which were removed go to?" The logical answer is that they must now be on some other object, causing it to be negatively charged. In other words, any object with more than its normal number of electrons is considered to be charged negatively. It has been proved experimentally that charged bodies act upon each other with a force of attraction when unlike charges are concerned, and a force of repulsion when like charges are concerned. From this observation it is concluded that electrons and protons attract each other; also, that electrons repel other electrons, and protons repel other protons. This force of attraction or repulsion changes with the magnitude of the charges and also with the distances between them. A law can be stated that charged bodies attract or repel each other with a force that is directly proportional to the product of the charges, and inversely proportional to the square of the distance between them. This law can be expressed as follows:

$$F = \frac{qq'}{d^2}$$

c. The unit of electrical charge could be taken as that charge associated with an electron or proton. This would not be practical due to its small magnitude. The practical unit of charge is called the coulomb, and is approximately equal to the charge on 6,280,000,000,000,000,000 electrons. It is easier to express such a large number by saying it is equal to 6.28×10^{18}. To understand this method of representing large numbers, the student should verify the fact that 500 is equal to 5×10^2, and that 520 is equal to 5.2×10^2, and that 5,200 is equal to 5.2×10^3. By actually verifying these relatively small

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numbers it will be easier to see how to represent very large numbers by this system.

4. Electrostatic or dielectric field of force.—*a.* The region surrounding and between charged bodies is called the dielectric field of force. Electrostatic field and electric field are other names given to this region of force. It is just as logical to call this region or space which is full of force a field of force, as it is to call a region or space which is full of corn or wheat a field of corn or a field of wheat. Since this force will act through free space or even through a vacuum, it can be seen that it is different from ordinary force and needs special consideration. Force can be applied by striking a sharp blow or exerting a steady pressure. It can also be delivered through connecting links, such as a chain or tow rope or can be evenly distributed over wide areas, such as the pressure of the water on a dam or the pressure of the air inside an automobile tire. These methods and others are more or less familiar to the average person, and all of them are applied directly or through some mechanical connecting link. A field of force differs from these in that it requires no physical or mechanical connecting link but can be applied through free space or even through a vacuum.

b. Fields of force permeate the space surrounding certain objects and, in general, diminish in proportion to the square of the distance from the source of origin. A field of force can be defined as a region or space where force is present. The force of gravity is a field of force that permeates the space surrounding the earth, and acts through free space causing all unsupported objects to fall to the earth. Newton developed the law of gravitation, which states that every object attracts every other object with a force that is directly proportional to the product of the masses and inversely proportional to the square of the distance between them. Notice the similarity between this law and the law of attraction of charged bodies. It is the gravitational field that holds the universe together. With no gravitational field the planets, including the earth, would, instead of revolving around the sun, fly off at a tangent, and travel through space on their own hooks. The moon would cease to revolve about the earth, and due to the earth's rotation, objects on its surface would be thrown out into space like mud from a bicycle wheel. The atoms are similar to our solar system in that electrons are revolving at a tremendous velocity around the positive protons of the atom. Since these revolving electrons do not fly off at a tangent, there must be a field of force between them and the protons. The reason that it must be a field of force is that there are no connecting links between the revolving

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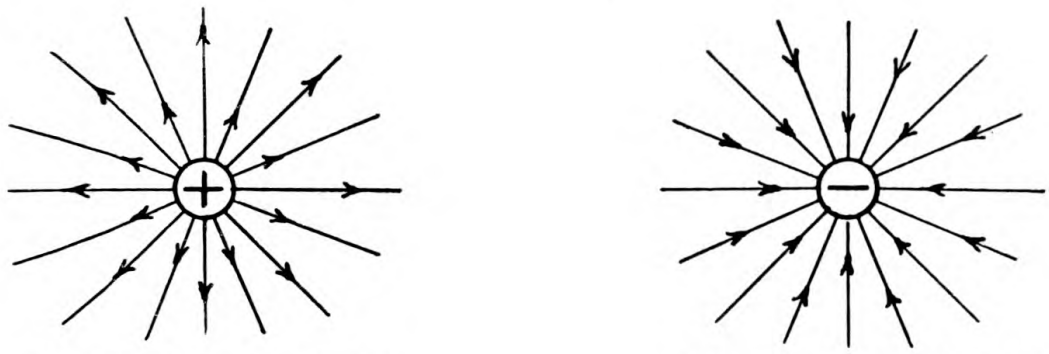
electrons and the protons of the nucleus. Relatively speaking, there are great distances between the electrons and the protons, even in apparently solid matter. It has been estimated that if a copper one-cent piece were enlarged to the size of the earth's orbit around the sun (approximately 186,000,000 miles), the electrons would be the size of baseballs, and they would be, on the average, 3 miles apart. The field of force between the electrons and protons in the atom is the same as the dielectric field associated with charged bodies. In practice when the dielectric or electrostatic field is spoken of, this interatomic field is not meant, but reference only is made to the external field about charged bodies.

5. Representing a field of force.—*a.* In order to visualize the various properties of fields of force and their relation to electrical phenomena, it is convenient to represent them by lines of force. These lines of force are imaginary lines used to represent the intensity and direction of the field under consideration. It is impossible to imagine enough lines to represent all the paths through space along which the force acts, and on paper only a very few can be drawn, and those only in one plane. But even so, if a few lines are drawn to give a general idea of the field's shape, direction, and relative intensity, something has been accomplished. The direction is indicated by an arrowhead and the field strength or intensity is indicated by the density or number of lines per unit area. The direction of a force can be taken as the direction a small test object moves or tends to move when acted on by the force. To get the direction of the current of a river, it would be better to test it with a cork or chip than just to make the general statement that the current is downhill, for at a bend eddy currents might be set up which would actually be flowing uphill. The cork or chip as a test object would check this. A test object for wind must be something light like a flag or column of smoke, but a test object for determining the direction of the earth's gravitational field must be a dense heavy object. By using a small heavy object like a brick, the earth's gravitational field can be tested for direction and will be found always to act toward the center of the earth. To test the direction of a dielectric field, the test object could either be a small positive charge or a small negative charge, because the force of a dielectric field will act on either. It has arbitrarily been agreed by all concerned to use a small positive charge when determining the direction of a dielectric field. In other words, the field about an isolated positive charge is away from the charge for a positive test charge would be repelled. The field about an isolated negative charge is toward the charge for

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a positive test charge would be attracted. The field between a positive and negative charge is from positive to negative for the same reason.

b. Figure 3 shows the dielectric field about isolated charges represented by lines of force.



① Dielectric field about a negative charge (electron).

② Dielectric field about a positive charge.

FIGURE 3.

c. Figures 4 and 5 show the resultant fields about like and unlike charges.

Note in figures 4 and 5 how the lines of force apparently repel each other. In figure 4, although the two charges are attracted, the lines

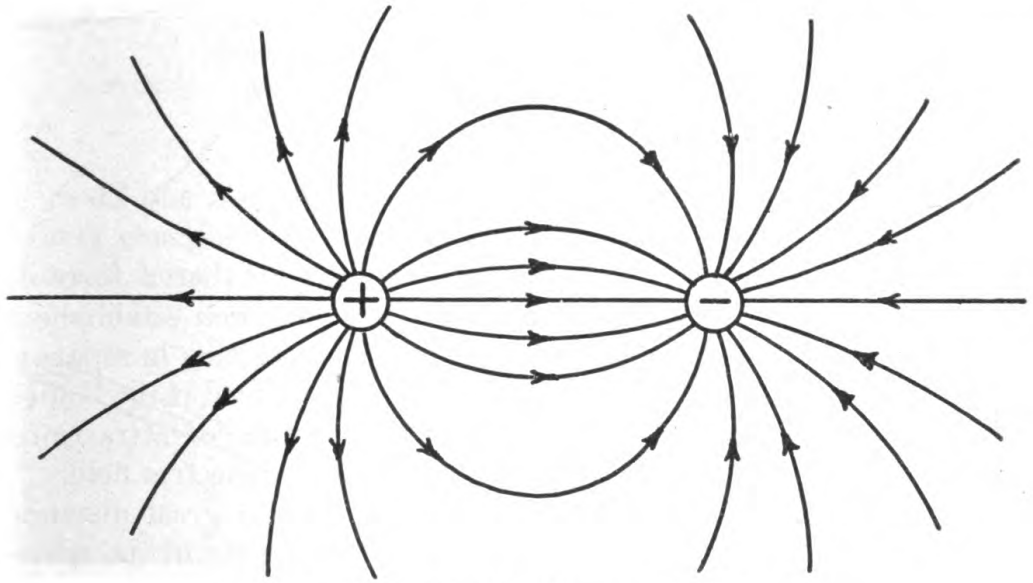


FIGURE 4.—Dielectric field about two unlike charges.

of force between the two are not parallel but bulge out at the center as if they were repelling each other. Also note that where they do this they are in the same direction, that is, from left to right on the paper. In figure 5 the lines of force which are in the region between

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the charges apparently are repelling each other as is evidenced by their being bent. Also these particular lines of force are in the same direction. Instead of saying like charges repel, the law can be stated: Dielectric lines of force in the same direction repel each other. In dealing with certain electrical phenomena this rule is very convenient and useful.

6. Experimenting with dielectric fields.—*a.* If a rubber rod or comb is briskly rubbed with a piece of fur or woolen cloth, a number of electrons from the fur or cloth adhere to the rubber. If the two are separated immediately, the rubber has an excess of electrons, or is negatively charged. If two pith balls are oppositely charged by touching one of them with the rubber and the other with the cloth or fur,

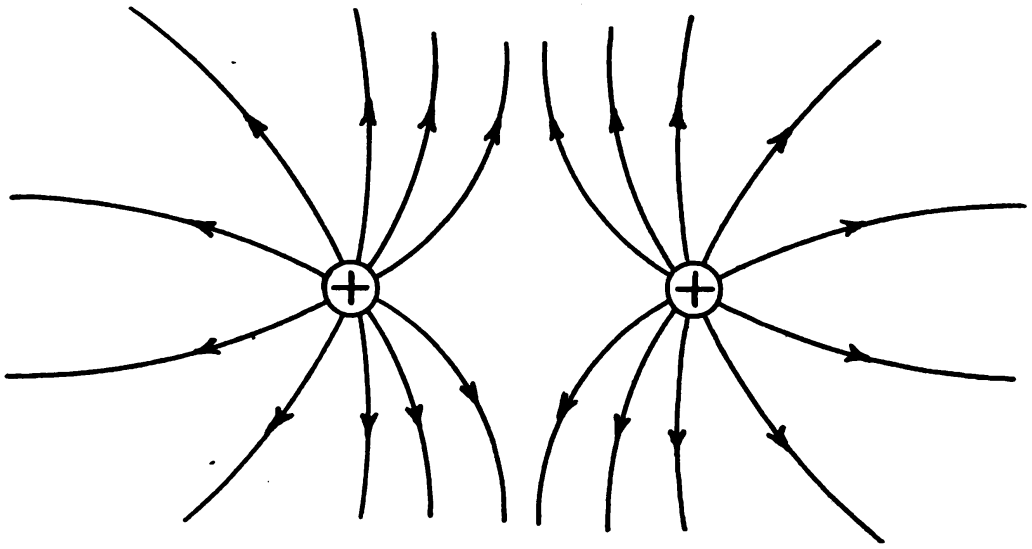


FIGURE 5.—Dielectric field about two like charges.

they will have an attraction for each other showing that a force is present. (See fig. 6.) Hence a dielectric field has been established. It was necessary to do work against the force of attraction in separating the charged bodies, but this energy would be regained if the bodies were allowed to come together as a result of the force of attractions between them. Hence, energy may be stored in a dielectric field.

b. If the negatively charged rubber rod be moved a great distance away from the cloth or fur, a dielectric field still exists in the space around it. This may be demonstrated by picking up bits of paper with the rod or by charging both of the pith balls from it. The pith balls now show a force of repulsion between them. This is still a dielectric field. (See fig. 7.)

c. If an external force is used to bring the two charged pith balls closer, work is done and the force of repulsion is increased, or the

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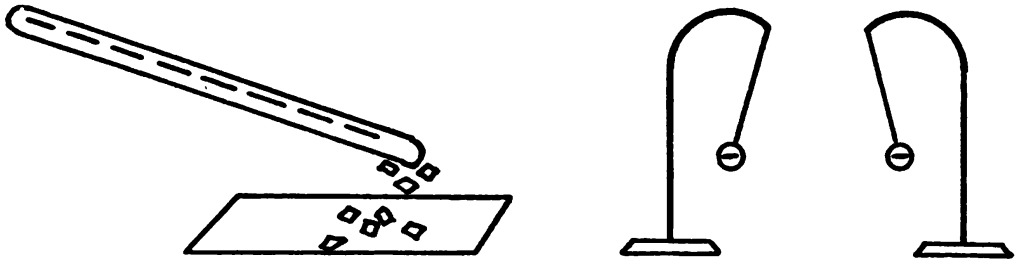
field is increased. The energy consumed in increasing the field is recovered when the external force is removed. It will be used up in returning the pith balls to their original positions. Here again it is



① Pith balls uncharged. ② Attraction between opposite charges.

FIGURE 6.

shown that energy is necessary to establish or increase a field, force is necessary to maintain it, and recoverable energy is stored in the field.



① Force of attraction of charge rod. ② Repulsion between similar charges.

FIGURE 7.

d. If one negatively charged pith ball is isolated and the negatively charged rubber rod is brought up toward it from any direction, a force of repulsion will be shown to be present. If the pith

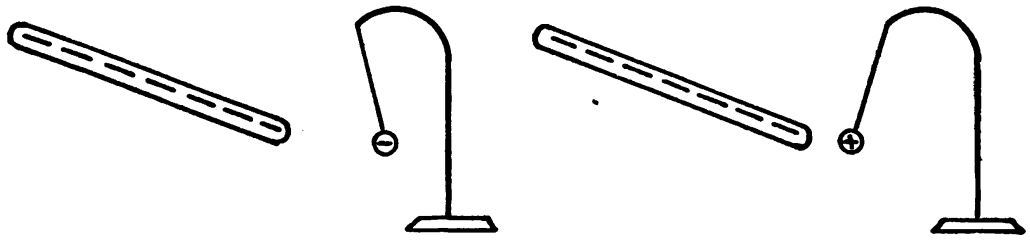


FIGURE 8.—Effect of field about a charged body.

ball had been positively charged, a force of attraction would have been noted no matter from which direction the negatively charged rod approached. (See fig. 8.) The conclusion, then, is that a dielectric field entirely surrounds a charged body.

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e. Many other striking and interesting experiments in connection with dielectric fields may be performed by using a static machine and the associated equipment which are usually found in physics laboratories. (See fig. 9.) One of these experiments which verifies the fact that there is no dielectric field inside a charged hollow sphere shows why shielded radio components are not affected by dielectric fields.

7. Potential.—Potential is "short" for potential energy and represents energy due to position. The water at the top of Niagara Falls possesses an enormous amount of potential energy due to its position. This potential energy is converted into kinetic energy as it falls. The amount of potential energy a certain quantity of water has at the top of Niagara Falls is equal to the work necessary to move that amount of water from the center of the earth to the top of the falls. This potential energy is really stored in the earth's gravitational field. Similarly, a point located in a dielectric field can be considered to possess an electrical potential or potential energy due to its position in the dielectric field, and can be measured by the work required to move a unit charge from infinity up to that point. If work must be performed in moving a positive charge up to that point, the point in question is at a positive potential. If work must be performed to move a negative charge to the point, it is at a negative potential. From the above consideration it can be seen that the units for potential are work or energy units per unit charge. In the case of electrical potential, the volt has been adopted as the unit and is equal to one joule per coulomb.

8. Potential difference.—*a.* In practice it is not the absolute potential that we are interested in but the difference of potential. In the case of Niagara Falls it is not the work that would result if the water at the top were to return to the center of the earth—this would represent the absolute potential of the water at the top; the problem is the work that results when the water moves from the top to the bottom of the Falls. Numerically, this is equal to the difference between the potential at the top of the Falls and that at the bottom. Likewise, in electricity it is the difference in potential between two points that is of importance.

b. This difference of potential is measured in volts and is equal to the work or energy necessary to move a unit charge from one point to the other point. If a unit charge is free to move, the difference of potential is equal to the energy expended by the field in moving the unit charge from one point to the other. In practice the only charges that are free to move are the free electrons in a conductor. If the

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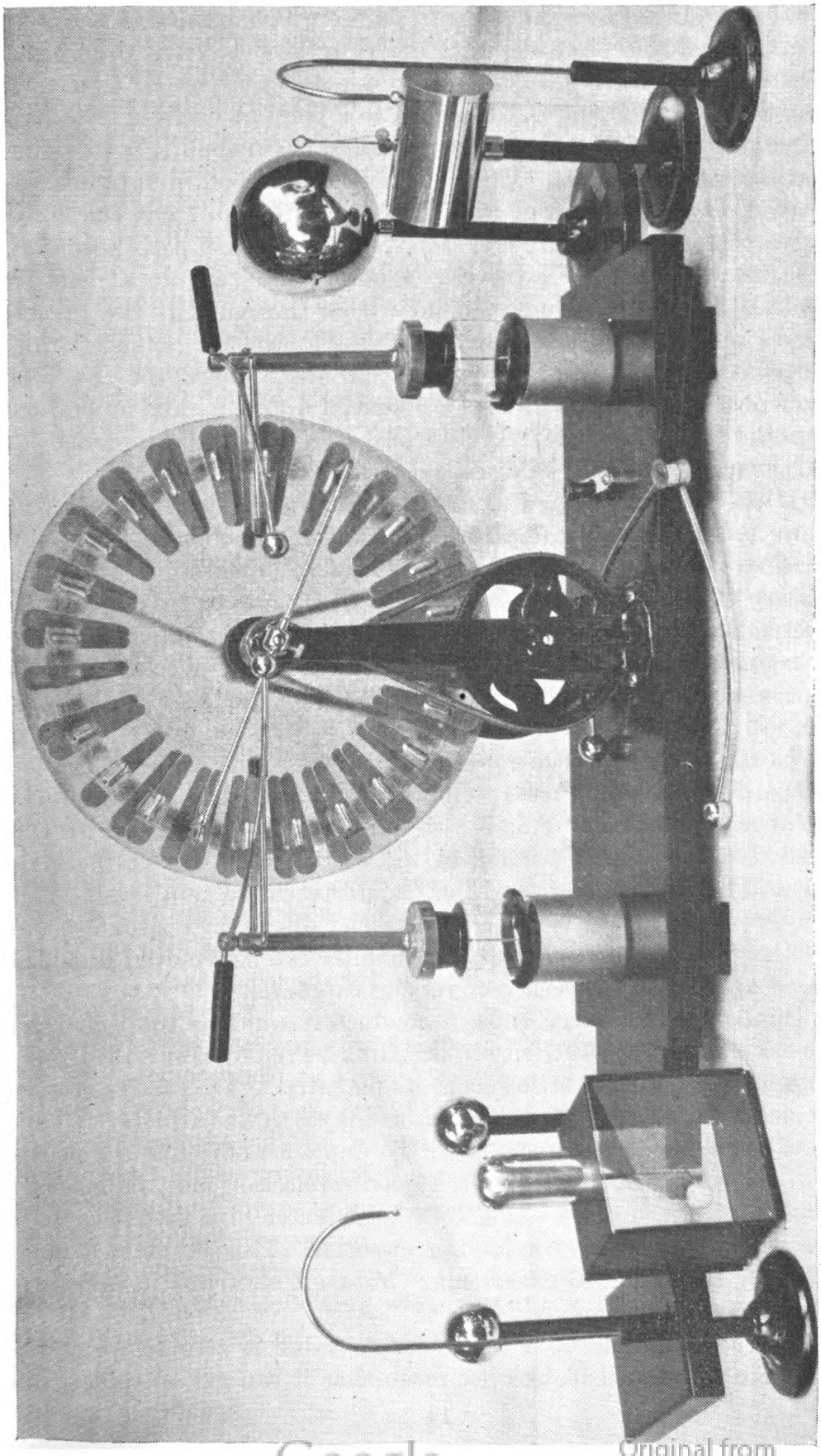


FIGURE 9.—Static generator and associated equipment.

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ends of a conductor are connected to points which are not at the same potential, the free electrons will move or flow toward the higher potential. That is, if one end of the conductor is connected to a point of negative potential and the other end to a point of positive potential, the free electrons will flow from negative to positive until both points are at the same potential. On the other hand, if both points are at a positive potential, then the free electrons will flow from the lower positive potential to the higher positive potential until both points are at the same potential. Likewise, if both points are at a negative potential, the free electrons will flow from the point at the greater negative potential to the point at the lesser negative potential until both points are at the same potential. In other words, the free electrons will flow as long as there is a potential difference and a conducting path. This flow of free electrons in a conductor is called an electric current and will be discussed later.

c. If no work is required to move a unit charge from infinity to a certain point, then according to the definition of potential that point is at zero potential. To find a point at zero potential, it would be necessary to go an infinite distance from all charges to get out of their dielectric field. It can be seen from the above that absolute zero potential has no practical meaning, but since there can be a positive and a negative potential there should be some place to refer to as zero potential.

d. In the case of mechanical potential energy, the water at the top of Niagara Falls would have to flow down to the center of the earth to be at zero potential. This is also impractical, so it was arbitrarily agreed that the largest portion of the earth which was at the same level, and hence the same potential, would be called zero level. This is sea level, for the oceans cover the majority of the earth's surface and are so large that millions of gallons of water can be removed or added without appreciably lowering or raising this level.

e. Similarly, if a large enough conductor could be connected, an immense quantity of electricity could either be removed or added without appreciably raising or lowering its potential. The earth's crust is just such a conductor. For this reason the earth has arbitrarily been agreed to represent zero potential. To put some object at the potential of the earth (zero potential), a good connection must be made to the soil moisture by connecting to a large water pipe system or to a large amount of buried conducting material. This is referred to as ground by the practical electrician. Most all electrical installations are grounded at some place.

f. Another example of a relative zero value is zero temperature. When zero is reached it does not mean that it can get no colder. It

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only means that the temperature has reached a value which a group of men arbitrarily agreed to call zero. In one system it is the temperature of melting ice.

9. Electromotive force (e. m. f.).—*a.* Electromotive force and electrical pressure are other terms used to express a difference in electrical potential. Electromotive force is the force that causes electricity to move through a conductor. As it is electrons that move, e. m. f. might better be called electron moving force which is nothing more than a dielectric field of force such as exists between points at different potential. Hence, a potential difference (p. d.) and an e. m. f. represent the same thing.

b. In the early days, electricity was considered to act like a mythical fluid that flowed through the wires similar to water flowing through a pipe. From this viewpoint, a pressure was required, hence the term "electrical pressure." This term is still used and represents the same condition as p. d. or e. m. f. Now potential, force, and pressure are not usually measured in the same units. It may seem strange that the volt, a unit of work per charge, can be used as a unit of force and a unit of pressure. Academically speaking, the volt is not the proper unit for force or pressure, but to the practical man, since p. d., e. m. f., and electrical pressure all represent the same set of conditions, the same unit will suffice.

c. Similarly, the pound is a unit of force and not a unit of pressure, but it is common to speak of so many pounds pressure in automobile tires. Also, the foot and the millimeter are both units of length or distance and not pressure, but such expressions as "a pressure of 30 feet," meaning the pressure resulting from water dammed up 30 feet high, or a "pressure of 730 millimeters," meaning the pressure required to support a column of mercury 730 mm. high, are frequently heard. The symbol usually used to represent a voltage, p. d., e. m. f., or electrical pressure is E. V is also used as a symbol for the volt.

10. Electric current.—*a.* An electric current is said to flow when the free electrons drift or move along a conductor. Electric current is a direct result of an e. m. f. and will continue as long as the e. m. f. exists between the ends of the conductor. The rate at which the electrons pass a given section of the conductor is a measure of the current's magniture, and is unity when unit quantity passes in unit time, that is, a coulomb per second.

b. This unit of current is called the ampere and can also be defined as the current that is flowing when 6.28 times 10^{18} electrons are passing a point each second. As was stated before, the charge from 6.28

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times 10^{18} electrons represents the quantity of electrical charge in a practical coulomb. The symbol that is usually used to represent electric current is *I*. *A* is also used as a symbol for the ampere.

11. Direction of current flow.—The free electrons which constitute an electric current flow from a point of low potential to a point of higher potential; that is, the free electrons are pulled or attracted toward the higher potential. In general, this would be from negative to positive, although as was explained before, it could be from positive to a greater positive or from a negative to a lesser negative value. In the early days of electricity, before anything was known of the electron theory, and electric current was considered to be the flow of some mythical fluid, naturally it was thought that the current would flow from a higher to a lower potential similar to the way water flows in a pipe connecting two reservoirs which are at different levels. Certain rules were developed on this wrong assumption, and even after the electron theory was developed authors were hesitant in changing the rules. Only in recent years have certain authors of radio texts developed new rules or changed the old ones as to the actual flow of current. The rules that need to be changed are very few and the changes very simple. The reason for changing the rules is that difficulty is encountered in presenting the vacuum tube theory from any other viewpoint than the electron flow. On the other hand, in connection with ordinary electrical phenomena the direction makes no difference. Exactly the same result will be obtained by either the old or the new conception of current flow. Nevertheless it is important for the student to understand the essence of the above discussion in order that no confusion will result from the use of either method of presenting the direction of current flow.

12. Resistance.—*a.* When an electric current flows through a conductor, the motion is relatively a slow drift, probably only a few inches per second. The slowness of the electron movement is due to the fact that the free electrons which constitute the current are constantly colliding with other electrons, protons, atoms, molecules, or the nucleus of atoms, consequently retarding their progressive motion toward a point of higher potential. On the other hand, it must not be thought that the actual velocity of individual electrons is low. If it were not for the constant collisions mentioned above, the electrons would actually reach velocities many, many times as great, and the magnitude of the current would be limited only by the time the e. m. f. was applied. This condition need not be considered as collisions take place in all conductors. Not only do these collisions retard the motion but set a limit to the magnitude of current (number of

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amperes) that will flow under a certain set of conditions. This opposition to the flow of current is called resistance, and as was mentioned before is one of the important electrical properties of matter.

b. The unit of resistance is the ohm. The value of the ohm may be defined in several ways. Since the volt and the ampere have already been defined it is a simple matter to define the ohm in terms of them. The ohm is that amount of resistance which will limit the current to 1 ampere when 1 volt is applied. In other words, 1 volt of e. m. f. can force 1 ampere of current through 1 ohm of resistance. R is the symbol usually used to represent resistance; $\sim$ is used as a symbol for ohm.

13. Laws of resistance.—*a.* The laws of resistance were first investigated by Ohm, who showed that the resistance of a given conductor varies directly as its length and inversely as the area of its cross section. He also showed that it depends upon the material of which the conductor is composed. This can be stated as follows: $R=\frac{KL}{S}$ where L is the length, S the area of the cross section, and K is a constant depending for its value on the material, the units used for L and S, and the temperature. In other words, for a given material and at a fixed temperature doubling the length causes the resistance to be twice as much or doubling the cross-sectional area causes the resistance to be just one-half what it was before.

b. The resistance of all substances changes as their temperature varies. The resistance of all metals increases as their temperatures rise; on the other hand, the resistance of most liquid and nonmetallic conductors decreases with an increase of temperature. The amount of change in resistance per ohm per degree is called the temperature coefficient.

c. Ability to prepare standards of resistance which should be independent of temperature is highly desirable. Certain alloys have practically a zero temperature coefficient, and are suitable for use in measuring instruments and where it is important that the value of resistance remain constant as the temperature changes.

14. Conductance.—As was stated previously, conductance is an electrical property of matter and is the reciprocal of resistance. The unit of conductance is the *mho* and the symbol is G. The relation of conductance and resistance can be expressed as follows:

$$G=\frac{1}{R} \text{ or } R=\frac{1}{G}$$

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15. Electrical power.—*a.* Power is defined as the rate at which energy is expended or as the rate of doing work. Hence a power unit is merely a work or energy unit per unit time. The foot-pound per minute and the joule per second are examples of power units. For measuring electrical power the watt has been adopted and is equivalent to a joule per second. W and P are both used as symbols for electrical power.

b. Many of the famous electrical experimenters, Volta, Ampere, Ohm, and Watt, have been honored by having an electrical unit named after them. In some cases, like the ampere and the watt, the name acts as a camouflage to the nature of the unit. The student must always bear in mind that the ampere and the watt represent a rate and must have time included in the definition.

c. There is a very important relation between e. m. f., current, and power. It can be developed in the following manner. By definition, power is the rate of doing work, or watts equal joules per second. This can be expressed as follows:

$$\text{watts} = \frac{\text{joules}}{\text{seconds}} \tag{1}$$

Current is the rate at which electricity flows, or amperes equal coulombs per second. This can be expressed as follows:

$$\text{amperes} = \frac{\text{coulombs}}{\text{seconds}} \tag{2}$$

E. m. f. or p. d., as was explained in a previous paragraph, is expressed in energy per unit charge, or volts equal joules per coulomb and can be expressed as shown below:

$$\text{volts} = \frac{\text{joules}}{\text{coulombs}} \tag{3}$$

Multiplying equations (2) and (3) and cancelling coulomb we have:

$$\text{volts} \times \text{amperes} = \frac{\text{joules}}{\text{coulomb}} \times \frac{\text{coulomb}}{\text{seconds}} = \frac{\text{joules}}{\text{seconds}} \tag{4}$$

But from equation (1),

$$\frac{\text{joules}}{\text{seconds}} = \text{watts}$$

Therefore, watts = volts × amperes. The same expressed in symbols gives an important formula for power: $W = EI$. This formula is very important and should be memorized. (See par. 28*b*.)

16. Practical units.—*a.* In many cases the fundamental units, such as the volt, ampere, ohm, mho, and watt, are either so large or so small as to involve very large or very small numbers, making a cum-

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bersome expression impractical to use. In any system one set of units is usually not sufficient. Ounces are used for small weights, and pounds or tons for larger weights.

b. In electricity, instead of having different names for the various magnitudes, various prefixes appear with the name of the unit. For example, a microampere is one one-millionth of an ampere; likewise, a micromho, a microvolt, etc., is one one-millionth of the fundamental unit. There are four of these prefixes used extensively in connection with electrical units. They are listed below with their relation to the fundamental unit:

Micro—.000001 or 10^{-6}
Milli—.001 or 10^{-3}
Kilo—1000 or 10^{3}
Meg—1,000,000 or 10^{6}
} times the fundamental unit.

c. The first step in becoming familiar with these practical units, such as the milliampere, kilowatt, megohm, or microvolt, is to memorize the above conversion factors. However, a student should not be satisfied with just memorizing the conversion factors. He should train himself to think directly in terms of the above units without going through the process of making a mental conversion. When a milliammeter is read, (a current meter calibrated in milliamperes) he should have an idea of the magnitude of the current without first dividing by a thousand to turn it into amperes.

d. When someone says a pencil weighs 2 ounces he does not divide by 16 and get ⅛ pound before he knows about how heavy it is, or when he reaches in his pocket and pulls out 3 cents, he does not first divide by 100 and get $0.03 before he knows how much he can buy. It is very important to become familiar not only with the fundamental electrical units but also with the milli, micro, kilo, and meg units used in practice.

SECTION II

BATTERIES

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17. General.—*a.* A battery is a device for converting chemical energy into electrical energy. A detailed explanation of just how energy can be stored in a chemical form in the battery ready to be converted into electrical energy and released in large or small amounts at a moment's notice is not the purpose of this section. Instead, the proper methods of using and caring for the different types of batteries will be considered.

b. Since batteries are one of the common household appliances used for flashlights, doorbells, and automobiles, the subject is not entirely a new one.

c. In addition to the uses mentioned above, the importance of batteries to industry and the commercial world can hardly be overestimated. Batteries are sometimes the only source of energy for light, power, and communications in times of emergency. They are an important part of the electrical equipment in aircraft, ships, and submarines.

18. Source of e. m. f.—When two dissimilar substances (called electrodes) are placed in certain solutions of acid or salts (called electrolytes), an e. m. f. is produced by the chemical action. This combination (electrodes and electrolyte) is known as a cell, and by its use chemical energy is directly converted into electrical energy. There are two general types of cells, primary and secondary. A battery is two or more cells connected so as to aid each other. The chemical action taking place in primary cells is of such a nature as to use up part of the ingredients. For this reason primary cells must be replaced in whole or in part after they have been in use for some time. The chemical action taking place in a secondary cell (storage cell) is of such a nature that if a current is sent backward through the spent cell a reverse chemical action takes place which restores the ingredients to their original form. This process is referred to as charging the cell.

19. Dry cells and dry batteries.—*a.* The term "dry cell" is misleading since the cell is not really dry. Instead of a liquid electrolyte, the active chemical is in paste form. This paste is placed in a zinc container and sealed with wax or some other type of seal so that externally the cell is dry. The dry cell is a primary cell, and once the chemicals are used up it must be replaced by a new cell. It cannot be recharged.

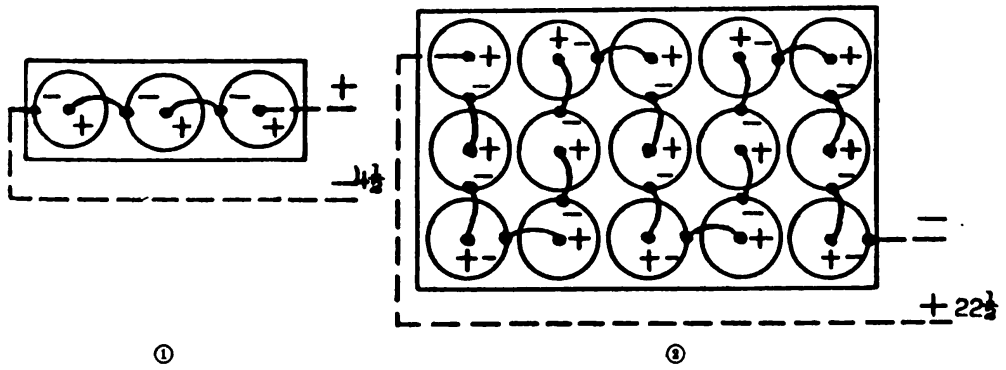
b. The ordinary dry cell has a carbon rod in the center for the positive electrode, and the zinc can is used for the negative electrode. This cell develops approximately 1½ volts on open circuit. This e. m. f. is due solely to the materials used and does not increase or decrease with size. The smallest flashlight cells still produce 1½

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volts. The larger cells have a longer life and can supply more current but do not give a higher voltage.

c. To obtain more voltage, a battery (2 or more cells) must be used. Flashlights are usually constructed to house batteries of two, three, or more cells. For radio purposes, dry batteries of 4½, 22½, and 45 volts are available. These batteries are merely a number of small 1½-volt cells connected in series and sealed in a paper carton. The 4½-volt batteries have 3 cells ($3\times1\frac{1}{2}=4\frac{1}{2}$), the 22½-volt batteries have 15 cells, and the 45-volt batteries have 30 cells. Figure 10① shows the connections of a 4½-volt battery. Note that + is connected to − except for the end terminals which serve as the + and − of the battery. Figure 10② shows a 22½-volt battery.

d. These batteries, B and C, are designed for circuits using only a small amount of current, so the small flashlight type cells are used. (See fig. 11.)



① ②

FIGURE 10.—Cell connections—4½-volt C battery and 22½-volt B battery.

For supplying circuits which require more current, either larger cells or a number of cells in parallel should be used. The maximum discharge current of an ordinary 6-inch dry cell should be limited to about ¼ ampere. If a circuit requiring 1 ampere is to be supplied by 6-inch dry cells, 4 cells should be connected in parallel so that each cell is only required to furnish ¼ ampere. (See fig. 12.)

If the above circuit required 1 ampere at 3 volts, 8 cells should be connected in series-parallel as shown in figure 13.

Figure 14① shows three 45-volt B batteries connected in series to give 135 volts.

Figure 14② shows the mistake which is sometimes made when three B batteries are connected to get 135 volts. True enough, there is no connection except from + of one battery to − of another battery, but if the circuit is carefully examined it will be seen that the center battery is acting as a short circuit for the other two, and a large

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FIGURE 11.—Various types of dry batteries.

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circulating current will very quickly discharge and ruin all three batteries. For circuits requiring more than a few amperes, storage batteries are usually employed.

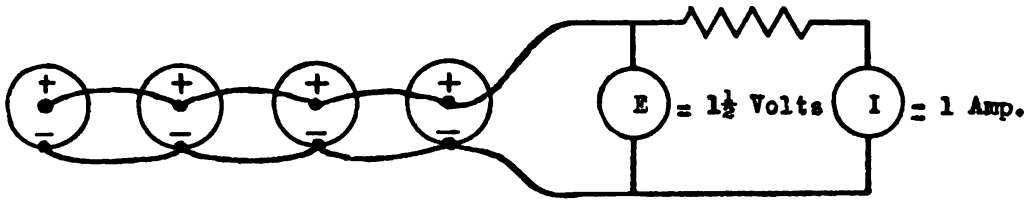


FIGURE 12.

20. Storage batteries.—Storage batteries consist of two or more secondary cells. These cells are of two kinds, lead acid and nickel iron alkaline. The nickel-iron type is called the Edison cell after

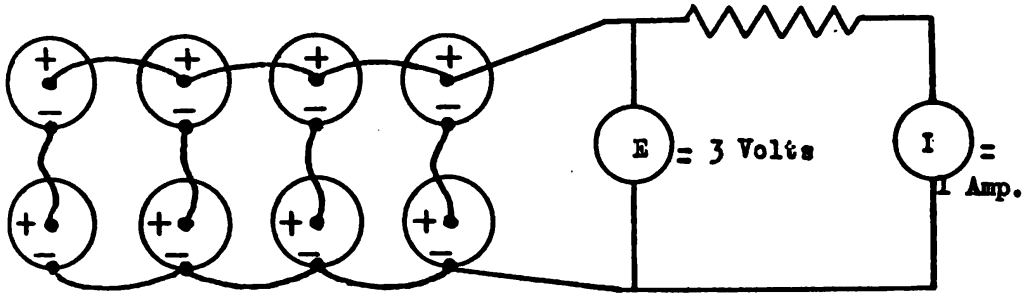


FIGURE 13.

its inventor. Edison batteries require less attention, are lighter in weight, and have much longer life than the lead-acid type. Even with the above-mentioned advantages, the lead-acid battery is used to a greater extent as will be explained later. (See fig. 15.)

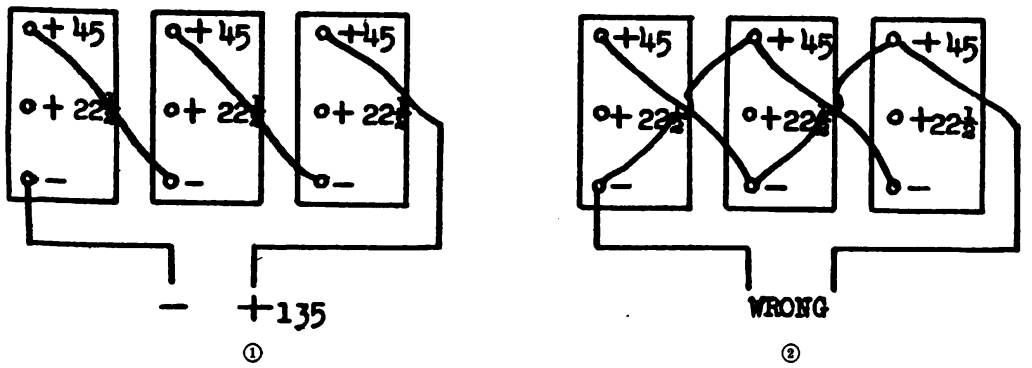


FIGURE 14.—Connecting B batteries in series.

21. Lead-acid battery.—The positive electrode of the lead-acid cell is composed of lead perioxide and the negative electrode is composed of spongy lead. The electrolyte is a dilute solution of sul-

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phuric acid. A storage cell contains electrodes, called plate, which are sandwiched together with wooden or other type insulators (called separators) separating the positive and negative plates. All the positive plates are connected together and all the negative plates are connected together. The usual storage battery is made up of 2, 3, or 6 cells connected in series and giving approximately 4, 6, or 12 volts, respectively. The common automobile battery is a 3-cell battery which usually contains 13, 15, or 17 plates. The Army airplane battery is a 6-cell battery and is called a 12-volt battery. In reality the voltage of a lead-acid cell is about 2.2 volts, so the so-called 6-volt batteries on open circuit have an actual voltage of 6.6 volts ($3 \times 2.2 = 6.6$). Rating, testing, charging, and the care of lead-acid storage batteries will be taken up later.

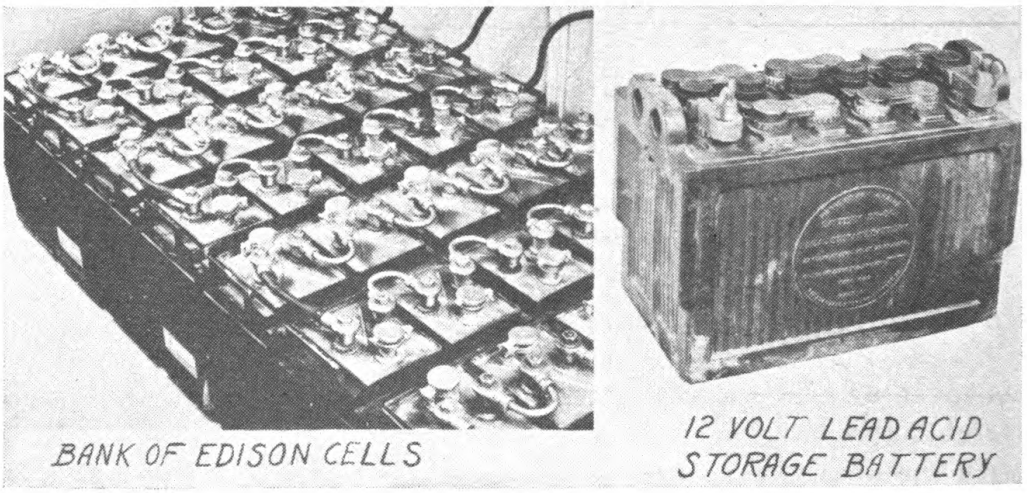


FIGURE 15.

22. Edison cell.—*a.* The Edison cell consists of plates of nickel oxide and iron with an electrolyte of caustic potash solution. Each cell container is made of heavily nickel-plated sheet steel, making a very rugged assembly. The individual cells are mounted in wooden trays and are connected to one another by copper connections provided with tapered steel lugs.

b. The density of the electrolyte does not change materially on charge or discharge, so that the state of charge of an Edison cell cannot be determined with a hydrometer as in the case of lead-acid cells. Each Edison cell has a voltage when fully charged of 1.2 volts and a voltage when discharged of 0.9 volts. Its state of charge should be tested by a voltmeter connected across its terminals. In large permanent installations the state of charge is usually obtained by employing an ampere-hour meter which is a permanent part of

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the charging and discharging circuit. It may be overcharged, discharged, or even short-circuited without injury to the plates. It will retain its charge for a long time and is not damaged by being left in a discharged condition. Edison batteries may be charged by the same methods to be specified for lead-acid storage batteries. Distilled water should be added from time to time to make up for evaporation of the electrolyte.

c. The Edison cell gives a lower voltage than the lead cell, occupies greater space for the same ampere-hour capacity, is more costly, has a higher internal resistance, and does not operate well at moderately low temperatures. On the other hand, it has a longer life, requires less attention, is much more rugged yet lighter in weight than the lead cell, and will stand a great deal of abuse without permanent injury.

23. Rating storage batteries.—Storage batteries are rated in ampere-hours. This means that a 100 ampere-hour battery can deliver 1 ampere for 100 hours, 100 amperes for 1 hour, or any other combination of amperes and hours, which, when multiplied together, gives 100. Batteries are also rated for maximum discharge current in amperes to keep from damaging the plates.

24. Testing lead-acid batteries.—*a.* As was stated above, the voltage of a fully charged lead-acid storage cell is about 2.2 volts. This voltage does not decrease uniformly as the cell is discharged, so a voltmeter is of little value for determining the condition of charge (i. e., how many ampere-hours are left). The method used to determine the condition of the cell as to its state of charge (i. e., discharged, ¼ charged, ½ charged, fully charged) is to test the specific gravity of the electrolyte with a hydrometer. The specific gravity of a substance is its comparative weight with respect to the weight of an equal volume of water. The weight of 1 cubic centimeter of pure water is 1 gram, so the weight of 1 cubic centimeter of a substance in grams is numerically equal to its specific gravity. The hydrometer is a device by which the specific gravity of a liquid can be read directly from a scale on a loaded float. (See fig. 16.)

b. When a lead-acid cell is fully charged, the specific gravity of the electrolyte should be 1.275 to 1.300 (the specific gravity of water is 1.000). The practical battery man, garage mechanic, etc., usually refer to the "gravity" as 1275 instead of 1.275. In fact, some battery hydrometers are marked with the decimal points omitted and others are marked "discharged," "¼ charged," "½ charged," "¾ charged," and "full charged." The reason that the specific gravity is greater than 1.000 is because sulphuric acid is heavier than water. Since acid

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is taken from the electrolyte by the chemical action during discharge, the solution becomes more dilute and hence the specific gravity decreases. In fact, when the cell is about ½ discharged, the specific gravity will be decreased to about 1.120. See figure 17, which shows a battery being tested with a syringe hydrometer or battery hydrometer.

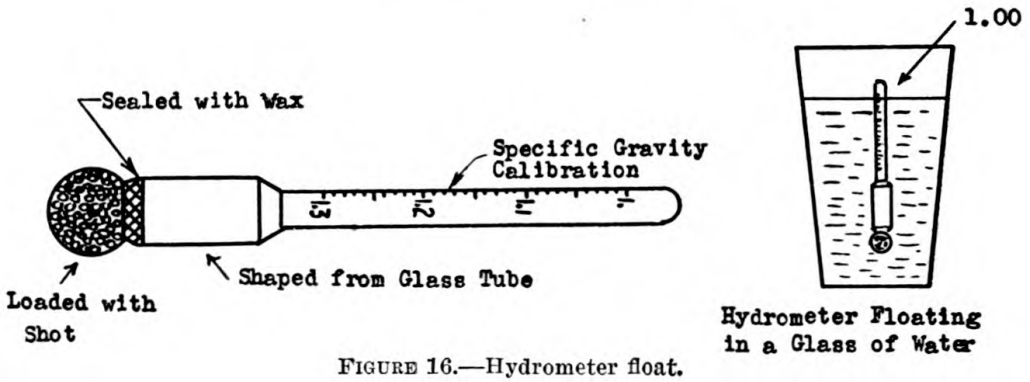


FIGURE 16.—Hydrometer float.

25. Charging and care of lead-acid storage batteries.—*a.* A discharged storage battery can be restored to its original state by passing a d. c. current through it in the direction opposite to the way the current flows while the battery is discharging. This process is

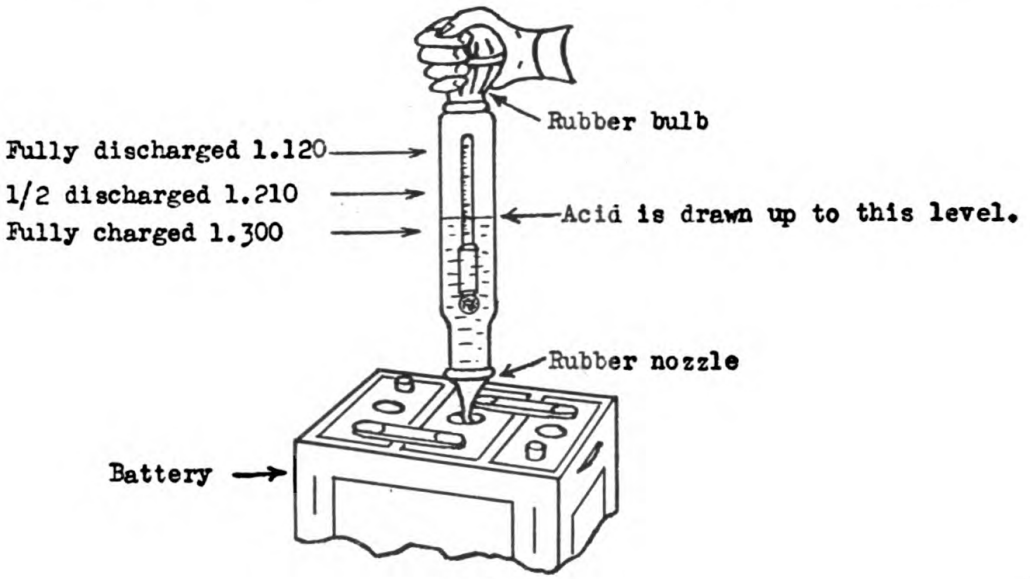


FIGURE 17.

called charging the battery. (See fig. 18.) In the figure, note that the + terminal of the generator is connected to the + terminal of the battery.

b. The ammeter and rheostat are included to adjust and observe the charging rate which is usually from 5 to 10 amperes. This is known

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as the constant current method of charging batteries. Various kinds of battery chargers are on the market, but they are all only a means of supplying a suitable d. c. voltage. If several batteries are to be charged at once they may be connected in series and a d. c. voltage slightly above the total voltage applied. Figure 19 shows a charger connected to five 6-volt batteries. This type charger is usually mounted on the wall and changes the 110-volt a. c. to d. c. of various

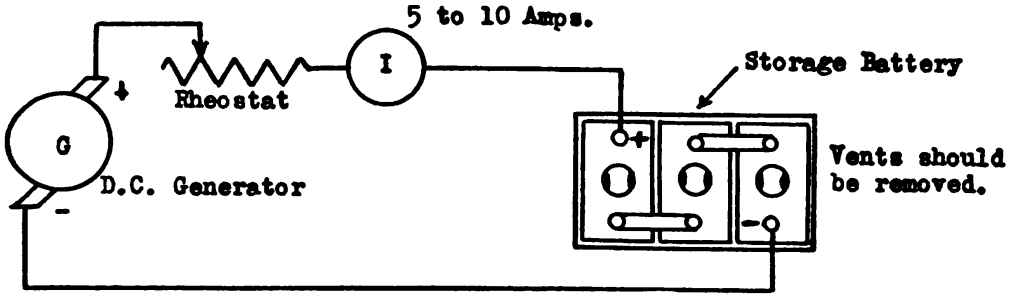


FIGURE 18.—Circuit for charging a storage battery.

voltages depending upon which contact the dial is set. When a low voltage high current generator is used to charge several batteries at once, they are connected in parallel.

c. Another method of charging batteries is known as the taper charge method. In this method, the charge is started at a very high

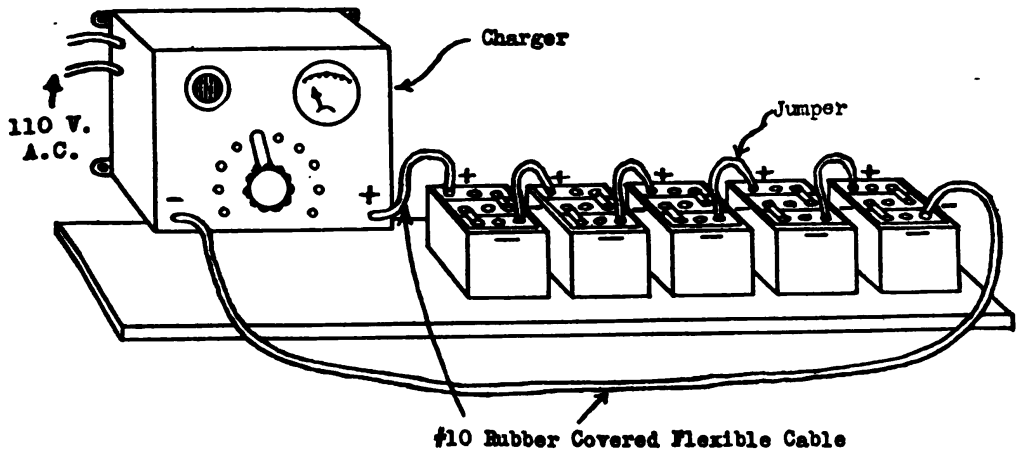


FIGURE 19.—Charging a bank of batteries.

rate and gradually tapered off as the battery becomes charged. This enables the battery to be charged in much less time than when the constant current method is used.

d. If a battery is to give good service and have a reasonably long life, the top must be kept clean and dry and the terminals free from corrosion. Pure distilled water (battery water) must be added at intervals to keep the level about 3/8 to 1/2 inch above the plates. The

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battery should not be left for any length of time in a discharged condition. Acid is not lost through the process of charging and discharging so none should be added unless electrolyte has been spilled. Water evaporates and is decomposed into hydrogen and oxygen gas, some of which is lost each time the battery is charged. This water must be replaced, but it is very important to use chemically pure water, for certain tap water (which may be excellent drinking water) contains iron or other chemicals which would ruin the battery. To keep the terminals from corroding they should be coated with clear vaseline.

SECTION III

SOLUTION OF CIRCUITS

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26. General.—*a.* A circuit is a closed path for something to go around and eventually return to the starting point. A source of e. m. f. is usually a part of an electric circuit.

b. The word "circuit" is used very loosely in connection with electricity. A circuit may be just one closed path or it may be a complete mesh of closed paths. In fact, a switchboard circuit or a radio receiver circuit is frequently spoken of; in either case the circuits of a switchboard or a radio receiver are meant.

c. In order to design electrical apparatus, it is important to understand thoroughly both magnetic and electric circuit computations. It is just as important to get the right amount and kind of iron in many electrical machines or devices as it is to get the right size wire or correct size and arrangement of the resistors or other devices.

d. As this is not a text on design, the solution of magnetic circuits will not be considered. On the other hand, the mathematical solution of simple electrical circuits is necessary to understand how elec-

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trical equipment functions. For this reason the solution of simple electrical circuits will be taken up in detail.

e. The only way to become proficient in solving problems is through practice. First, thoroughly learn the rules and formulas, then practice using them. Following through examples which are worked out in detail in a text and watching an instructor solve problems on the blackboard have their value but are not enough. Memorizing "cut and dried" procedure for type problems is not recommended. Instead the student should learn to analyze the problem, carefully noting the values given and the ones which are to be found. These unknowns should be carefully considered as to their relation to each other as well as to the known values, for one of these unknowns may help get others and should be obtained first. The various rules and formulas which apply to the unknowns should be considered mentally

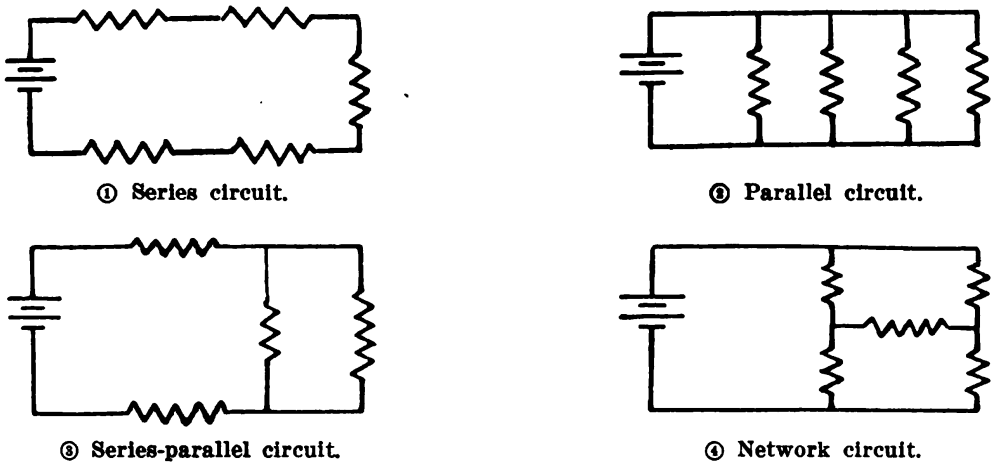


FIGURE 20.—Types of circuits.

to determine which ones have possibility and, where several methods would give the result, to decide which method is the simplest.

f. Practicing the above procedure is what makes one really proficient in the solution of problems. If each step in an example in a text can be followed, and the problems seem easy when the instructor solves them on the blackboard, yet trouble is encountered in solving similar problems which are slightly different, more practice is needed in analyzing problems to determine "when to use which formula and what to do next." The first step in solving any circuit problem is to decide in what classification the circuit belongs.

27. Classifying circuits.—*a.* Circuits can be divided into four general types or classifications: Series, parallel, combination or series-parallel, and network. Figure 20 shows five resistors connected in different ways.

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(1) Series circuits are those which have only one closed path. In other words, all the devices which constitute the circuit are connected one after the other so that the end of one is connected to the beginning of the next, and so on.

(2) Parallel circuits are those which have all of the devices connected so that half of the ends are fastened to a common point or conductor and the other half fastened to another common point or conductor.

(3) Series-parallel circuits are those which have certain devices connected in series and others in parallel.

(4) Network circuits or simply networks are those circuits which cannot be divided into a number of series and parallel parts. In other words, certain of the devices are neither in series nor parallel with any of the other devices.

b. Even complicated networks may be solved by applying Ohm's and Kirchoff's laws in conjunction with the solution of simultaneous algebraic equations. Ohm's law and some simple rules developed from Kirchoff's law are all that are necessary for solving series, parallel, and series-parallel circuits. The complete solution of networks is beyond the scope of this text and is not necessary for an elementary study of electricity.

28. Ohm's law; power formulas.—*a. Ohm's law.*—(1) In 1826, Ohm announced the discovery that the current which flows in a circuit is directly proportional to the electromotive force and inversely proportional to the resistance. This can be expressed algebraically as follows:

$$I=\frac{E}{R} \text{ or amperes}=\frac{\text{volts}}{\text{ohms}}$$

Transposing the above equation, the following is obtained:

$$E=IR \text{ and } R=\frac{E}{I}$$

These are very important relations and should be learned thoroughly.

(2) Ohm's law applies to a whole circuit or to any part of a circuit. Of course, when Ohm's law is applied to the whole circuit, R must be the equivalent resistance. On the other hand, when dealing with only a part of a circuit, E must be the e. m. f. across that part of the circuit. R must be the resistance of that part of the circuit, and I must be the portion of the current that flows through that part of the circuit. In any event, the fundamental units must be used, that is, the volt, ohm, and ampere. If milliamperes, megohms, etc., are used, the result will be incorrect.

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(3) When measuring the voltage at different points in a circuit, it is found that the voltage is less as more resistance is included between the source of power and the points where the measurement is made, provided a current is flowing through the resistance. To illustrate this, consider figure 21, which represents a battery furnishing current through a resistor to light a lamp.

(4) The total voltage of the battery is equal to the potential difference between *A* and *B*. The voltage available to light the lamp is the potential difference between *C* and *D* which will be less than the battery voltage. There is said to be a voltage drop due to the current flowing through the resistor. Since it is caused by *I* flowing through *R*, it is referred to many times as an *IR drop*. The amount of this drop is calculated from the Ohm's law formula, E (drop) $= I \times R$ (causing drop). The resistance that causes the drop in voltage may be the resistance of the connecting wires or even the internal resistance of the battery or other source of electrical power. Unless otherwise stated,

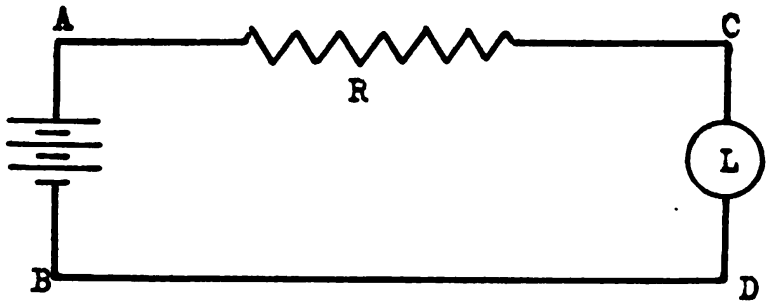


FIGURE 21.—Circuit illustrating voltage drop.

the connecting wires and batteries used in this text are assumed to have zero resistance.

(5) On the other hand, if the lamp's filament were to burn out, the current would cease to flow, and regardless of the size of resistor *R* the voltage between *C* and *D* would be exactly the same as that of the battery. No drop in voltage occurs unless current is flowing. From the above it seems that voltage across a resistor is caused by the current flowing through it. In fact, it is common to hear expressions such as the voltage produced by the current flowing through a resistance. Of course, statements such as the above are not strictly correct, since it has already been shown that the potential difference or voltage is the *cause* and the current is the *result*. Nevertheless, this is an academic issue only, and if the practical man wants to think of an *IR* voltage being caused by a current flowing through a resistance, it is satisfactory.

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(6) Another way to consider IR voltage drops in a circuit is to think of them as being components of the total applied voltage. In figure 21, the total battery voltage would be divided into two components: the IR voltage appearing across the resistor and the voltage appearing across the lamp. This voltage across the lamp is also an IR voltage for, after all, the filament of a lamp is only a piece of resistance wire. In any system, the total is always equal to the sum of all the components. In other words, the sum of the voltage across the resistor and the voltage across the lamp is equal to the battery voltage. This will be explained further when Kirchoff's laws and series circuits are taken up.

b. Power formulas.—(1) A formula for power was developed in paragraph 15. Using this formula in conjunction with Ohm's law formulas, two other power formulas can be obtained. If IR is substituted for E in the formula $W=EI$, the formula $W=I^2R$ is obtained. The expression I^2R is used many times to represent power, and the student should become so familiar with the expression that if he sees or hears it, he will immediately think of power or watts.

(2) If, instead of substituting IR for E in $W=EI$, $\frac{E}{R}$ is substituted for I, another formula for power will be obtained:

$$W=\frac{E^2}{R}$$

(3) Since energy can neither be created nor destroyed and power is the rate at which energy is expended (energy per second), then power cannot be destroyed. For this reason it can be seen that the total power supplied to a circuit must equal the sum of the individual powers used by each device in the circuit regardless of the type of circuit. This can be expressed as $W_t=W_1+W_2+W_3+$etc., where W_t is the total watts and W_1, W_2, W_3 are the individual watts.

29. Kirchoff's laws.—*a.* Kirchoff reasoned, before anything was known about electrons and protons or of the real nature of electric current, that at a point in any type of circuit there was just as much current flowing away from the point as was flowing to it. This was substantiated by experiment, and the electron theory also indicates that the statement is true. More electrons could not leave a point than were coming to the point for in a short time there would be no free electrons at the point to leave it. On the other hand, more electrons could not flow to a point than were leaving for eventually the conductor would swell up and burst at this point.

b. If the current flowing toward a point is considered + and the current flowing away from the point is considered −, then Kirchoff's

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current law can be stated in a single short sentence: The algebraic sum of all the currents flowing to a point in any type circuit is zero.

c. Kirchoff further reasoned that, since a point in a circuit cannot have a difference of potential with respect to itself (the same point cannot be at two different potentials), if the potentials were measured at various intervals around any closed path or loop of any type circuit or network, the sum of all the rises in potential must necessarily be equal to the sum of all the falls or drops in potential. A rise in potential means that the next point along a circuit is at a higher potential than the previous one, just as a fall or drop in potential means that the next point along a circuit is at a lower potential than the previous one. Either a rise or drop of potential is measured in volts and is equal to the amperes of current flowing between the two points times the ohms of resistance between the two points for $E=IR$. The expression "IR drop" is a very common one and has already been discussed.

d. Another way to state the above law is to say that around any closed loop the sum of all the potential differences or voltages in one direction is equal to the sum of all the potential differences or voltages in the opposite direction. If voltages in one direction are considered to be plus (+) and voltages in the opposite direction are considered to be minus (−), then Kirchoff's voltage law can be summed up by a single short sentence similar to the current law: The algebraic sum of all the voltages around a closed loop of any type circuit is zero. This law has been verified experimentally.

e. Just memorizing Kirchoff's laws is not enough. Instead, an understanding of the above reasoning is of much greater value in analyzing and understanding the operation of electrical equipment.

f. Instead of using the basic laws which apply to any type circuit or network, it is usually more convenient to use rules developed for special types of circuits. Hence, for solving series circuit problems there are a few rules and formulas for series circuits only. Likewise, certain rules and formulas apply to parallel circuits only.

30. Solving simple problems.—Many problems merely require the choosing and application of a single formula for their solution. The following examples are of this type:

Problem 1.—How much current is required to light a 50-watt bulb when used in a 110-volt circuit?

Solution.—Consider all the formulas until one is found which contains power, current, and voltage, for voltage and power are given and current is the unknown. $W=EI$ is such a formula. Since I is desired, this formula can be transposed to read $I=\frac{W}{E}$.

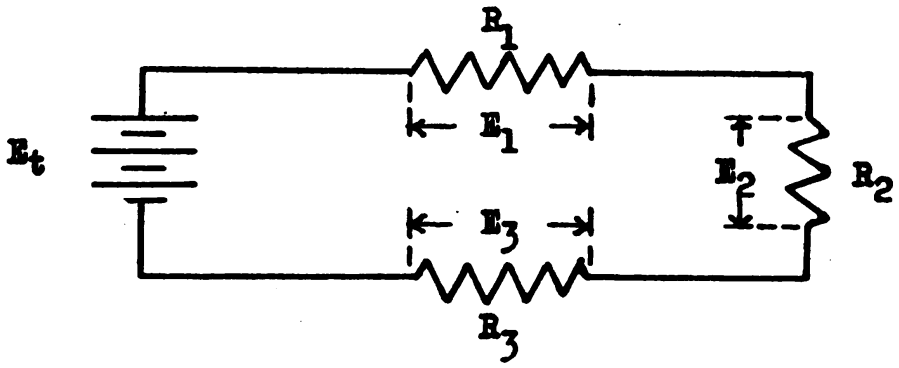
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Substituting the values in the formula and performing the indicated arithmetic, the result is: $I=\frac{50}{110}=.454$ ampere.

Problem 2.—What is the resistance of a toaster element which operates from 120 volts and draws 2 amperes of current?

Solution.—Again it is only necessary to find a formula containing voltage, current, and resistance. The Ohm's law formula or $R=\frac{E}{I}$ gives the solution. Substituting and solving: $R=\frac{120}{2}=60$ ohms.

31. Series circuit rules and formulas.—*a.* A series circuit has only one closed path with no point where the current can branch off. For this reason, since Kirchoff's current law states that just as much current leaves a point as enters it, the current flowing through each resistor or component of a series circuit is the same. This can



①

FIGURE 22.—Resistors in series.

be stated as $I_t=I_1=I_2=I_3=$etc., where I_t is the total current furnished by the source of power; I_1 is the current flowing through the first resistor R_1, or the first component; I_2, I_3, etc., represent the currents flowing through resistors R_2, R_3, etc., or the corresponding components which constitute the circuit.

b. Kirchoff's voltage law when applied to the single closed path of a series circuit verifies the following statement: The total voltage applied to a series circuit is equal to the sum of the voltage components or drops across the different resistors or devices of the circuit. This is stated algebraically as $E_t=E_1+E_2+E_3+$etc. (See fig. 22 ①.)

c. From Ohm's law $E_t=I_tR_t$; $E_1=I_1R_1$; $E_2=I_2R_2$, etc. If these values are substituted in the above equation and the I's eliminated, since they are all equal, the formula for the total resistance of a series circuit becomes $R_t=R_1+R_2+R_3+$etc., or may be stated thus: The total

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resistance of a series circuit is equal to the sum of the individual resistances.

d. If a number of equal resistors are connected in series, it can easily be proved that the voltage across each resistor will be the same and equal to the total voltage divided by the number of resistors. If there are N resistors then:

$$\frac{E_t}{N}=E_1=E_2=E_3=\text{etc.}$$

Also the total resistance in this case will be equal to the number of resistors multiplied by the value of one resistor. If there are N equal resistors then $R_t=NR$.

32. Solving series circuit problems.—*a.* The solution of a series circuit is a straightforward process and no difficulties are usually encountered. Since the current is the same in any part of the circuit, and the total resistance is merely equal to the sum of the individual resistances, series circuit problems usually have an individual voltage or resistance as the unknown.

b. To find an unknown voltage the usual procedure is to find the total resistance. Use Ohm's law to find the total current, and since this current is equal to the current through the part where the unknown voltage is to be found, it can be used in the formula $E=IR$ to obtain the desired voltage. Be sure that the R in the formula is the resistance of the part of the circuit across which the voltage is to be found.

c. When an unknown resistance is to be found, one of several procedures is necessary depending on the other values of the circuit which are given. If a logical procedure is used in the application of Ohm's law and the rules for series circuits, no difficulty will be encountered.

33. Series circuit examples.

Problem 1.—Find the voltage across R_3 in the following circuit:

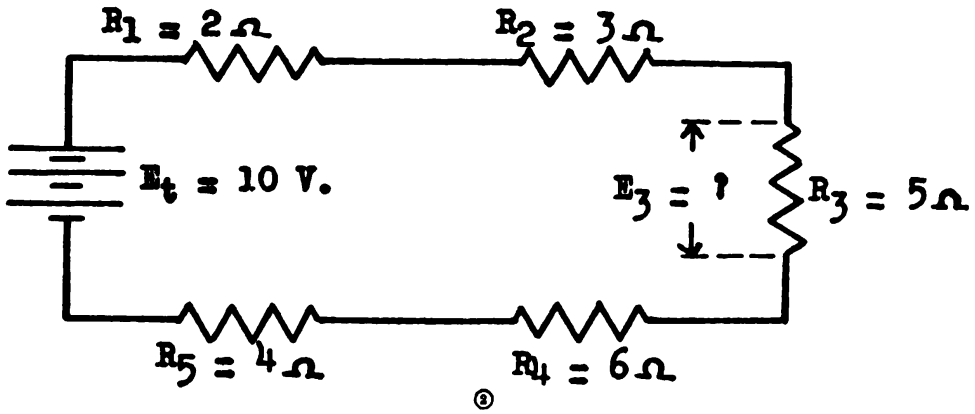


FIGURE 22.—Continued.

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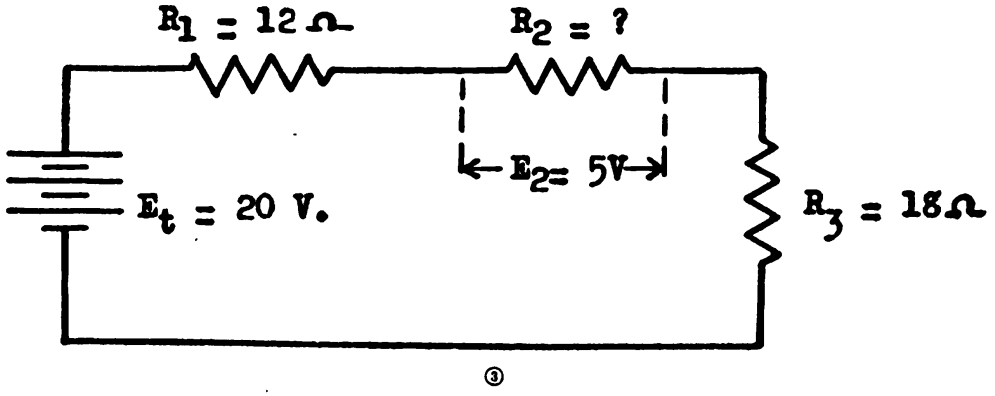
Solution.—If I_3 were known, E_3 could be found, for $E_3=I_3 R_3$, and R_3 is known. Also if E_1, E_2, E_4, and E_5 were known, E_3 could be found because this is a series circuit. So $E_t=E_1+E_2+E_3+E_4+E_5$ or, transposing, $E_3=E_t-(E_1+E_2+E_4+E_5)$. The second formula is ineffective, for although E_1, E_2, E_4, and E_5 can be found, the same method could be used to get E_3 in the first place. In other words, any method that will give E_1 will also give E_3. Refer to the first formula and remember that this is a series circuit. $E_3=I_3R_3$ or $E_3=5I_3$, for $R_3=5$. In a series circuit all the I's are she same. Hence, if any I is found, the problem is solved. Now I_1, I_2, I_4, or I_5 is just as difficult to find as I_3 for the corresponding R's but not the E's are known. On the other hand, I_t can be found, for E_t is known and R_t can be found:

$$R_t=R_1+R_2+R_3+R_4+R_5$$
$$R_t=2+3+5+6+4=20$$
$$I_t=\frac{E_t}{R_t}=\frac{10}{20}=0.5 \text{ ampere.}$$

But as was shown above, $I_3=I_t$; therefore $I_3=0.5$ ampere. Substituting this value of I_3 for E_3, then $E_3=5I_3=5\times0.5=2.5$ volts.

Suppose the above problem had been stated thus: Given $E_3=2.5$ volts, find E_t. Of course the answer will be 10 volts, but the entire solution should be gone through.

Problem 2.—Find R_2 in the following circuit:



③

FIGURE 22.—Continued.

Solution.—From Ohm's law, $R_2=\frac{E_2}{I_2}=\frac{5}{I_2}$. If any I is known, the solution to this problem can be found, because all the currents are the same in a series circuit. Since no two corresponding values of voltage and resistance are given, so it might seem that the value of I cannot be found. But R_1 and R_3 are given, and although E_1 and E_3 are not, their sum can be found, that is, $E_1+E_3=20-5$ (Why?). Also,

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$R_1+R_3=12+18$. As Ohm's law is valid when any sets of corresponding values are used, the equation can be written:

$$I=\frac{E_1+E_3}{R_1+R_3}=\frac{15}{30}=0.5 \text{ ampere.}$$

Now returning to the first formula considered, R_2 is found as follows:

$$R_2=\frac{E_2}{I_2}=\frac{5}{I_2}=\frac{5}{5}=10 \text{ ohms.}$$

Problem 3.—A flashlight bulb requires 2.5 volts and 60 milliamperes of current to light it. Calculate the resistor required to enable it to be operated from a 6-volt battery.

Solution.—First, the circuit must be selected and drawn. In order to protect a 2.5-volt bulb, it will be necessary to place the resistor in series to produce a voltage drop as shown below.

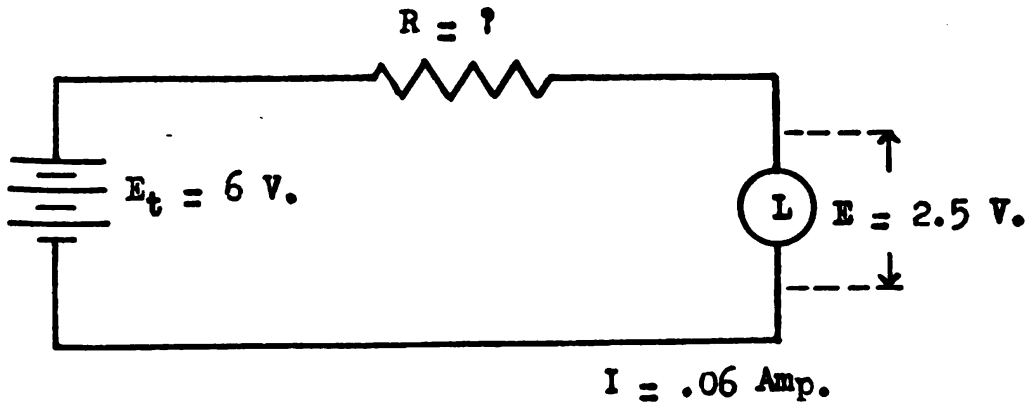


FIGURE 22.—Continued.

Next, the voltage across the bulb and the current through it should be indicated. The current must be in amperes. To convert 60 milliamperes to amperes, it is merely necessary to move the decimal point three places to the left.

Applying Ohm's law: $R=\frac{E}{I}$ or $\frac{E}{0.06}$. In this case E is neither 6 nor 2.5 but, instead, $6-2.5=3.5$ volts. (Why?)

Substituting: $R=\frac{3.5}{0.06}=58.3+$ ohms.

34. Parallel circuit rules and formulas.—*a.* A parallel circuit has all of its resistors or components connected between two points or conductors (fig. 23). It can easily be seen that if the potential difference between A and B (fig. 23) is a certain value, then the potential difference or voltage across each resistor or component of the

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parallel circuit is this same value for they are all connected between these two points. Since all the voltages of a parallel circuit are equal to the same thing they are equal to each other; that is, all of the voltages of a parallel circuit are equal, or $E_t=E_1=E_2=E_3=$etc.

b. If the components are connected between conductors, such as *C* and *D* (fig. 23), the same statement holds, provided the conductors are relatively large and short; in other words, if the resistance of the conductors is small enough to be negligible. This is always considered to be the case in circuit diagrams unless it is a long power line and the resistances of the wires are specifically mentioned.

c. If figure 23 is redrawn by merely stretching it out a bit (fig. 24), the current relations can be seen easier. From Kirchoff's current law the total current entering point *A* must be equal to the total current

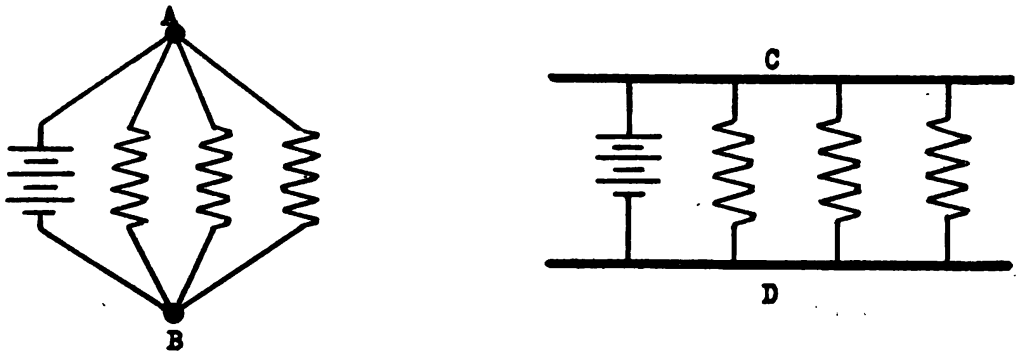


FIGURE 23.—Parallel circuits.

leaving the same point. In this case I_t is entering point *A* while I_1, I_2, and I_3 are leaving the point. Therefore, $I_t=I_1+I_2+I_3+$etc., or for a parallel circuit the total current is equal to the sum of the individual currents.

d. There are several methods of developing a formula for the total equivalent resistance of a parallel circuit.

From Ohm's law: $R_t=\frac{E_t}{I_t}$. It has already been shown that $I_t=I_1+I_2+I_3+$etc. If this is substituted in the above formula and the *E*'s are eliminated since they are all equal in a parallel circuit, the well-known formula for the total resistance of a parallel circuit is obtained:

$$R_t=\frac{1}{R_1+R_2+R_3+\text{etc.}}$$

In other words, to find the total resistance of a parallel circuit it is merely necessary to find the reciprocal of the sum of the reciprocals of the individual resistances.

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c. In case a number of equal resistances are connected in parallel, the current will divide equally and be equal to the total current divided by the number of resistors. If there are N resistors then—

$$\frac{I_t}{N}=I_1=I_2=I_3=\text{etc.}$$

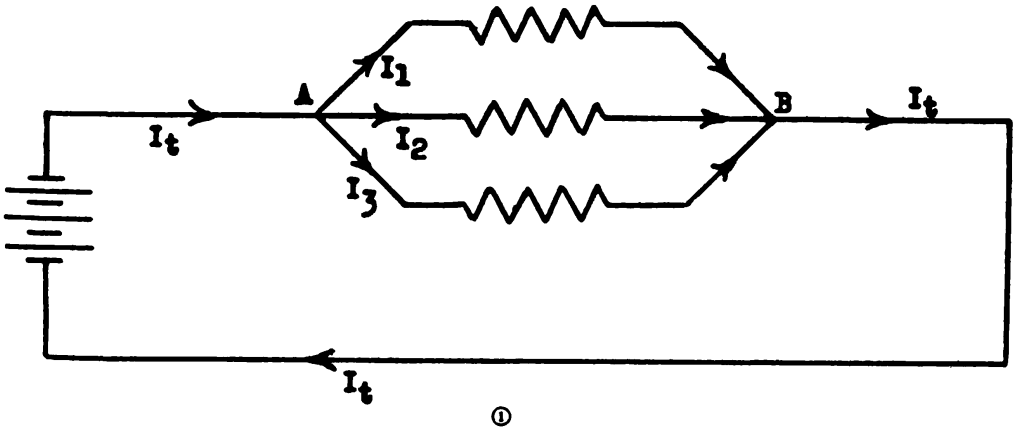


FIGURE 24.—Current division in a parallel circuit.

In the case of N equal resistances, $R_t=\frac{R}{N}$ where R is any one of the equal resistors.

35. Solving parallel circuit problems.—*a.* Parallel circuit problems are very simple since the voltages are all the same and the current divides in inverse proportion to the various branch resistances.

b. An unknown current can be found by first finding the total current and applying the inverse proportion rule. Often it is easier to get the unknown current by finding the voltage and applying Ohm's law to the individual branch circuits.

c. An unknown resistance can usually be found by applying Ohm's law. Of course, it may be necessary first to find the total resistance to get the voltage.

36. Parallel circuit examples.

Problem I.—Find the total current flowing from the battery in the circuit shown below:

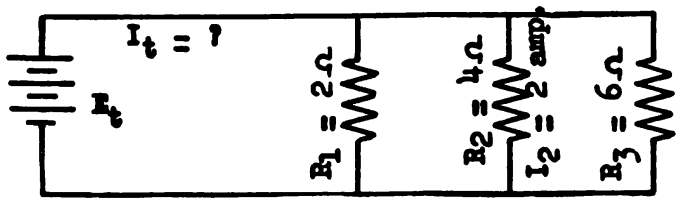


FIGURE 24—Continued.

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Solution.—First note that it is a parallel circuit and consider the various formulas which might be of use in finding I_t.

Ohm's law states that $I_t=\frac{E_t}{R_t}$. The value R_t can be found from the formula:

$$R_t=\frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}}$$

but E_t is not given.

Another formula for the total current in a parallel circuit is $I_t=I_1+I_2+I_3$. The value I_2 is given but I_1 or I_3 is not. From Ohm's law, $I_1=\frac{E_1}{R_1}$ and $I_3=\frac{E_3}{R_3}$. So in order to find I_1 and I_3, E_1 and E_3 are needed. At this point it should be remembered that in a parellel circuit all of the voltages are equal. If E_1 or E_3 could be found, so could E_t as they are all equal. It thus appears that the voltage is necessary to solve the problem.

Ohm's law states that $E=IR$ when corresponding I's and R's are used. Looking over this circuit again it is observed that there is only one set of corresponding I's and R's given, that is, I_2 and R_2. Therefore, $E_2=I_2R_2=2\times4=8$ volts. E_1, E_3, and E_t are each equal to 8 volts.

Now there are two methods to choose from: Either R_t can be found and divided into 8 volts, or I_1 and I_3 can be found and then added to I_2 which is given. The second method involves less arithmetic.

$$I_1=\frac{E_1}{R_1}=\frac{8}{2}=4 \text{ amperes.}$$

$$I_3=\frac{E_3}{R_3}=\frac{8}{6}=1.33 \text{ amperes.}$$

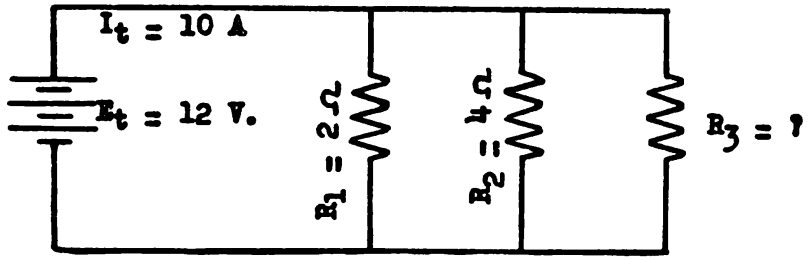
$$I_2=2 \text{ amperes (given).}$$

$$I_t=I_1+I_2+I_3=4+2+1.33=7.33 \text{ amperes.}$$

The student should verify this answer by the other method. Also it would be good practice to solve the problem if it were restated: $I_t=7.33$ amperes. Find I_2.

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Problem 2.—Find R_3 in the circuit shown below.



③

FIGURE 24—Continued.

Solution:—From Ohm's law $R_3=\frac{E_3}{I_3}=\frac{12}{I_3}$.

(Why is E_3 equal to 12 volts?)

$I_3=I_t-(I_1+I_2)=10-(I_1+I_2)$. (Why?)

But $I_1=\frac{12}{2}=6A$ and $I_2=\frac{12}{4}=3A$. (Why?)

$I_1+I_2=6+3=9A$ and $I_3=10-9=1A$.

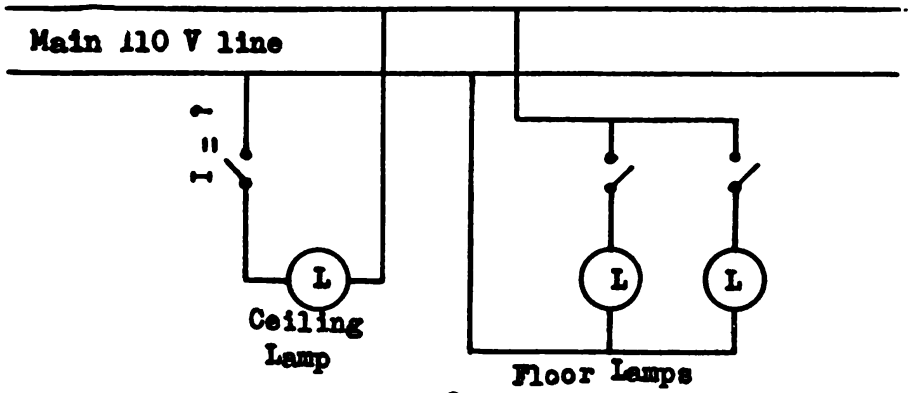
Therefore, $R_3=\frac{12}{1}=12$ ohms.

Problem 3.—What is the total power consumed by the lamps in a room which has one 75-watt bulb in the ceiling fixture and two 100-watt floor lamps if all are turned on and operating from a 110-volt supply? (Note each lamp has an independent switch.)

Solution.—Since in any type of circuit $W_t=W_1+W_2+W_3+$, etc., the power consumed will be $W_t=75+100+100=275$ watts.

Problem 4.—In problem 3 how much current must the ceiling fixture wiring carry?

Solution.—Since each lamp has an independent switch, the lamps must be connected in parallel for if they were in series, one switch would turn out all the lamps. (Why?) Draw a sketch of the circuit.



④

FIGURE 24.—Continued.

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R can be found from the formula $W=\frac{E^2}{R}$ for by transposing this formula, $R=\frac{E^2}{W}$, W for the ceiling lamp is 75 watts, therefore,

$$R=\frac{(110)^2}{75}=\frac{12{,}100}{75}=161.3+ \text{ ohms.}$$

Substituting the values in the first step above:

$$I=\frac{110}{161.3}=0.68+ \text{ ampere.}$$

An easier way to find the above answer would be to spend more time considering various formulas and their possibilities instead of continuing with the first method thought of.

The formula $W=EI$ gives the quickest solution. Transposing this formula we get:

$$I=\frac{W}{E}=\frac{75}{110}=0.68+ \text{ ampere.}$$

37. Series-parallel circuit rules and formulas.—*a.* For solving series-parallel circuits, no additional rules or formulas are necessary. Since a series-parallel circuit is made up of a combination of components in series and components in parallel, series circuit rules and formulas can be applied to the series parts of the circuit, and parallel rules and formulas can be applied to the parts of the circuit which are in parallel with each other.

b. Any combinations of resistors may be replaced by their equivalent value, as found by applying a series or parallel circuit formula as the case may be, without altering any voltage, current, or power in any other part of the circuit. (See fig. 25 ① and ②.)

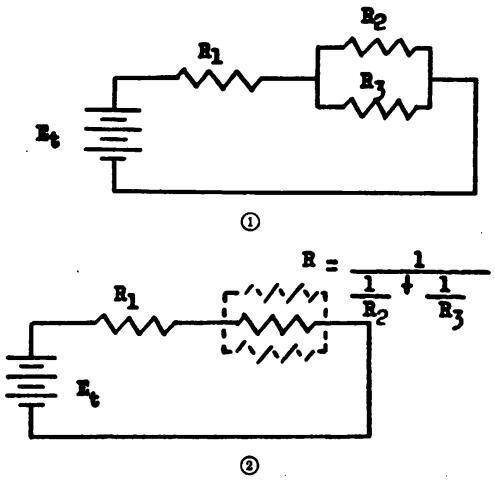


FIGURE 25.

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The original circuit is shown in figure 25 ①. R_1 will have a certain voltage across it, a certain current through it, and will dissipate a certain amount of power depending on the size of R_1, the voltage of the battery, and also the size of R_2 and R_3. Since the combinations R_2 and R_3 are in parallel with each other they can be replaced by the equivalent resistor R shown in figure 25 ② and equal to:

$$\frac{1}{\frac{1}{R_2}+\frac{1}{R_3}}$$

without affecting any value associated with R_1. So to find anything concerning R_1 it is merely necessary to solve the circuit shown in figure 25 ②, which instead of being a series-parallel circuit is only a series circuit, whose total resistance $R_t=R_1+R$ and whose total current $I_t=\frac{E_t}{R_t}$. But $I_t=I_1$ for the currents of a series circuit are the same. Hence, $I_1=\frac{E_t}{R_t}$. Also $E_1=I_1R_1$ and $W_1=E_1I_1$, $I_1^2R_1$ or $\frac{E_1^2}{R_1}$.

c. To find voltages, currents, or powers associated with R_2 or R_3 it is necessary to revert to the original circuit for all except the voltages. E_2 and E_3 can be obtained from either circuit.

38. Solving series-parallel circuit problems.—*a.* The first step in the solution of a series-parallel circuit is to segregate the various combinations which are in parallel or in series even to the extent of redrawing the circuit to make these combinations stand out almost as if they were separate units.

b. The next step is to apply series or parallel rules and formulas to these segregated combinations to get equivalent values. Here again it may be desirable to redraw the circuit again, using these equivalent values in place of the original values.

c. The above procedure will eventually lead to the total equivalent resistance of the circuit which in turn can be used in connection with the total voltage to obtain the total current. From this point it is usually necessary to revert to the original circuit to obtain voltages across or currents through the various parts of the circuit. Do not be misled by thinking the first thing to do in the solution of a series-parallel circuit is to get the total resistance or the total current.

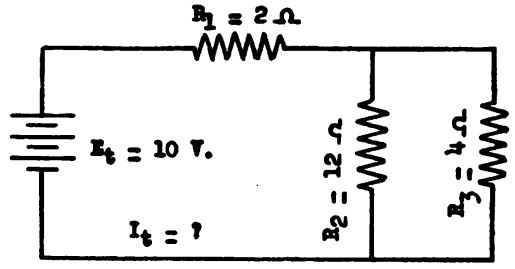
d. It is impossible to give definite procedure methods to apply in the solution of this type circuit. The arrangements and the quantities to be found are of too wide a variety. The methods outlined in the beginning of this section must be used in order to cope successfully with the solution of series-parallel problems. Never-

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theless a detailed solution of a few typical examples should be helpful.

39. Series-parallel circuit examples.

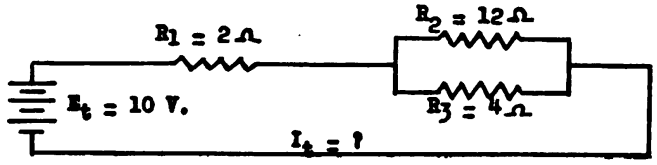
Problem 1.—Find the total current flowing from the battery shown below:



③

FIGURE 25—Continued.

Solution.—From Ohm's law, $I_t=\frac{E_t}{R_t}=\frac{10}{R_t}$. It is only necessary to find R_t. R_2 and R_3 are in parallel, for two of their ends go to one point and the other two ends go to another common point. If it is not obvious that these two resistors are in parallel, compare the above circuit with the circuit as it is redrawn below:



④

FIGURE 25—Continued.

If it is evident that R_2 and R_3 are in parallel, it is not necessary to redraw the circuit. Applying the reciprocal formula to the combination of R_2 and R_3:

$$R_{2-3}=\frac{1}{\frac{1}{R_2}+\frac{1}{R_3}}=\frac{1}{\frac{1}{12}+\frac{1}{4}}$$

$$=\frac{1}{\frac{4}{12}}=\frac{12}{4}=3 \text{ ohms.}$$

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The circuit can now be redrawn with the parallel combination replaced by the 3 Ω equivalent resistor.

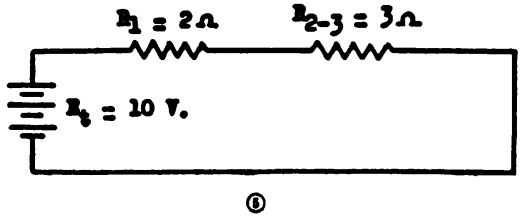


FIGURE 25—Continued.

Since the circuit is a series circuit, it is only necessary to add the two resistors to obtain the total. Hence, $R_t = R_1 + R_{2-3} = 2 + 3 = 5$ ohms. Returning to the first Ohm's law formula considered at the beginning solution, substitute the 5 Ω for R_t. Then $I_t = \frac{10}{5} = 2$ amperes.

Problem 2.—Find the voltage across R_2 in the circuit shown below:

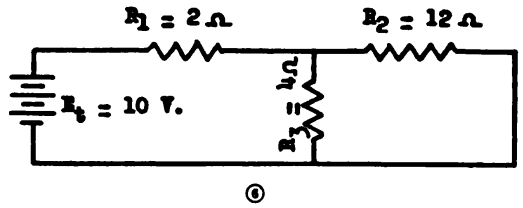


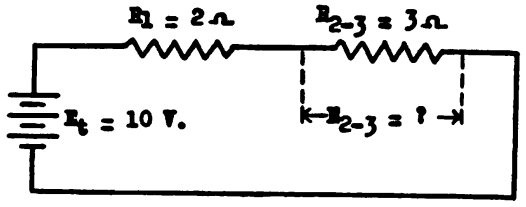
FIGURE 25—Continued.

Solution.—The first step is to segregate the various groups. At first it might seem that R_1 and R_2 or R_1 and R_3 are in series, but this is not the case because in either case there is a place to branch off. R_2 and R_3, however, are in parallel with each other. (Why?) Compare this circuit with the ones for the previous problem. After a careful comparison the conclusion should be reached that the two circuits are identical. Applying Ohm's law: $E_2 = I_2 R_2 = I_2 \times 12$. It is only necessary to find I_2 and multiply by 12 to get the solution. I_2 could be found by recalling the fact that the current divides through the parallel branches of a circuit inversely proportional to the resistances. If this method is used I_t would be required.

An easier method than this would probably be to consider the circuit which replaces R_2 and R_3 with their equivalent resistance of 3 Ω. (See problem 1.) Since R_2 and R_3 are in parallel the voltage across either is the same, and this value is the same as would be across their

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equivalent resistance. This means that we can merely find the voltage across the 3 Ω resistor of the circuit shown below to find E_2.

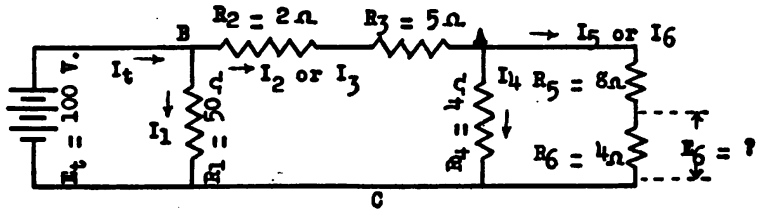


⑦

FIGURE 25—Continued.

From Ohm's law: $E_{2\text{-}3}=I_{2\text{-}3}\times R_{2\text{-}3}$. Since in a series circuit all the currents are the same, $I_{2\text{-}3}=I_t$. The method of finding I_t was given in problem 1 and was found to be 2 amperes. Therefore, E_2, which is equal to $E_{2\text{-}3}$, can be obtained by substituting in the above formula. Hence, $E_2=E_{2\text{-}3}=2\times3=6$ volts.

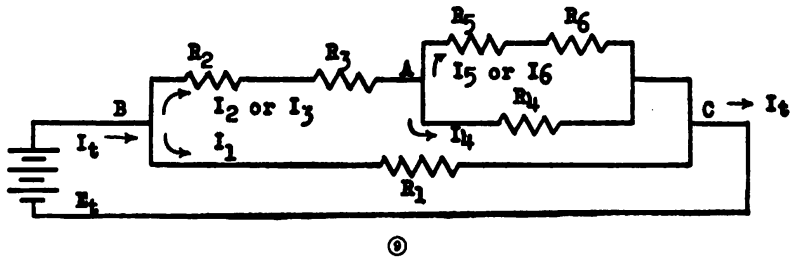
Problem 3.—Find the voltage across R_6 in the following circuit:



⑧

FIGURE 25—Continued.

Solution.—Note that the circuit is a series-parallel circuit, having R_5 and R_6 in series with each other; R_2 and R_3 in series with each other; the equivalent of R_5 and R_6 in parallel with R_4; the equivalent of R_4, R_5, and R_6 in series with R_2 and R_3, and the equivalent of R_2, and R_3, R_4, R_5, and R_6 in parallel with R_1. If necessary, in order to see the above, redraw the circuit stretching it out as shown below:



⑨

FIGURE 25—Continued.

Training will enable one to see at a glance which parts of the circuit are in series and which are in parallel without redrawing it.

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Next, consider the various formulas which will give E_6; that is, from Ohm's law, $E_6=I_6R_6$, or from Kirchoff's voltage law, the closed path containing E_t and E_6. This gives the equation: $E_t=E_2+E_3+E_5+E_6$ or, transposing, $E_6=E_t-(E_2+E_3+E_5)$.

In the Ohm's law formula, R_6 is given but not I_6, and in the Kirchoff's law formula, E_t is given but none of the other voltages. To get E_2, E_3, and E_5, the corresponding currents will be needed for $E=IR$. If I_5 were known, I_6 would be also, and hence E_6, for R_5 and R_6 are in series which means the current through them is the same.

From the above consideration it is necessary to find I_6; to assist, place arrows and label them to represent the various currents. (See diagrams.) Applying Kirchoff's current law at point A, it is seen that I_2 or $I_3=I_4+I_6$, or $I_6=I_3-I_4$ or I_2-I_4. The difficulty here is that neither I_2, I_3, nor I_4 is known; $I_2=\frac{E_2}{R_2}$ but neither E_2, E_3, nor E_4 is known. In fact the only known voltage is E_t. At this point note that the voltage between points B and C is the same as E_t. This voltage is the voltage applied to combination R_2, R_3, R_4, R_5, and R_6. If an equivalent resistance for the above resistors could be found, so could the current flowing through that equivalent resistor. Also this current would all flow through R_2 and R_3. This seems to be on the right track. To get this equivalent resistance, redraw the circuit between points B and C after R_2 and R_3 have been added to give an equivalent of 7 ohms and R_5 and R_6 have been added to give an equivalent of 12 ohms.

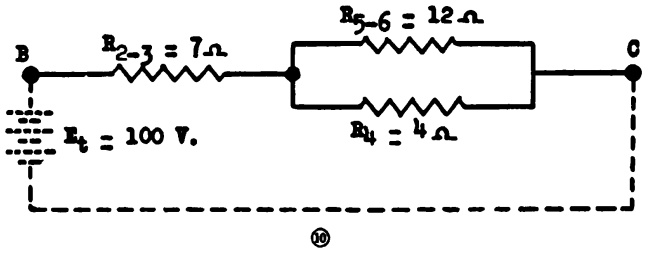


FIGURE 25—Continued.

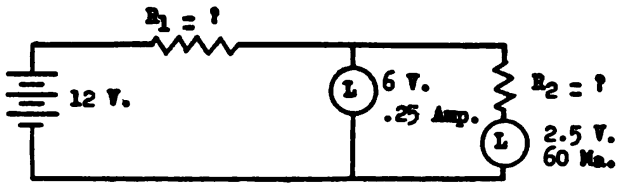
By combining certain parts of a series-parallel circuit and omitting other parts, the resultant circuit becomes a much simpler one to work with. Note that in the above circuit I_6 is the current that flows through the 12 Ω resistor labeled R_{5-6}. (The battery was dotted in to indicate the 100 volts between points B and C.)

The above circuit is identical to the circuits in figure 25 ① and ② and also to the circuits in problems 1 and 2 which have already been

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taken up in detail. The student should review the discussion of these circuits and finish the solution of this problem himself. The answer to the problem is: $E_6 = 10$ volts.

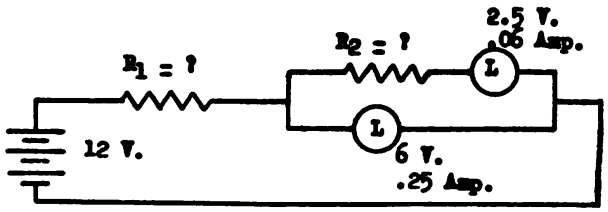
Problem 4.—If two pilot lamp bulbs are to be operated as shown below, what values should R_1 and R_2 have? What power does each resistor dissipate?



⑪

FIGURE 25—Continued.

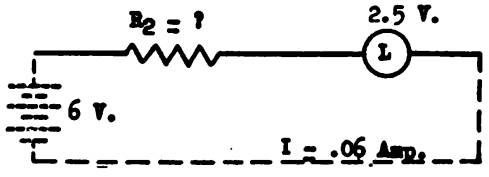
Solution.—There are several methods of approach to a problem of this nature. First note that R_2 and the 2.5-volt lamp are in series. This combination in turn is in parallel with the 6-volt lamp. The combination which includes R_2 and both lamps is in series with R_1. The circuit may be redrawn as shown below:



⑫

FIGURE 25—Continued.

Substitute 0.06 ampere for the 60 milliamperes before using in a formula. Since there are 6 volts across the one lamp there must also be 6 volts across R_2 and the other lamp. (Why?) This can be redrawn as a separate problem as shown below. (The 6-volt battery is dotted in to represent the 6-volt component that is present in the actual circuit.)



⑬

FIGURE 25—Continued.

$$R_2 = \frac{E_2}{I} = \frac{E_2}{.06}$$

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As this is a series circuit $E_2=6-2.5=3.5$ volts. Therefore, $R_2=\frac{3.5}{.06}=58.3+$ ohms.

$R_1=\frac{E_1}{I_1}$. In this case $I_1=I_t$, and the total current is equal to the sum of the two branch currents which are given. Therefore,

$$I_t=.25+.06=.31 \text{ ampere.}$$

Also, $E_1=E_t-E$ (parallel combination). It has already been shown that E (parallel combination) is equal to 6 volts. Therefore

$$E_1=12-6=6 \text{ volts.}$$

Referring to the Ohm's law equation, $R_1=\frac{6}{.31}=19.3+$ ohms.

In order to find the power dissipated by R_1 and R_2, any of the power formulas can be used. From above, $E_1=6$ volts and $I_1=0.31$ ampere. Then the power dissipated by R_1 is: $W_1=E_1I_1=6\times.31=1.86$ watts. Also it was shown above that $E_2=3.5$ volts, and I_2 is the same as the current required for the 2.5 volt lamp. Therefore,

$$W_2=E_2I_2=3.5\times.06=0.21 \text{ watt.}$$

The student should verify the above power answers by using I^2R and $\frac{E^2}{R}$ power formulas.

SECTION IV

MAGNETISM

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Magnetic poles	43
Attraction and repulsion of magnetic poles	44
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Solenoids	48
Polarity of electromagnets	49
Resultant magnetic fields	50
Magnetic units	51
Magnetization curve	52

40. Magnetic field of force.—*a.* As was shown before, electrical energy can be stored in a dielectric field of force. Electrical energy can also be stored in a magnetic field of force. A certain amount

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of energy is required to produce a magnetic field and after it has been produced it requires a force to maintain it. When this sustaining force is removed, the field dies down or collapses and in so doing gives up the same amount of energy that was required to produce it. Hence, while the field was in existence it stored an amount of energy equal to that required to produce it.

b. A magnetic field of force permeates the space about certain objects and all current carrying conductors. Also, there is a magnetic field about the earth as is evidenced by the action of a compass, a small device whose pivoted needle always points in a general north-south direction due to the force of the earth's magnetic field. In fact the compass needle has a magnetic field of its own which reacts with the earth's magnetic field thereby causing the needle to swing around.

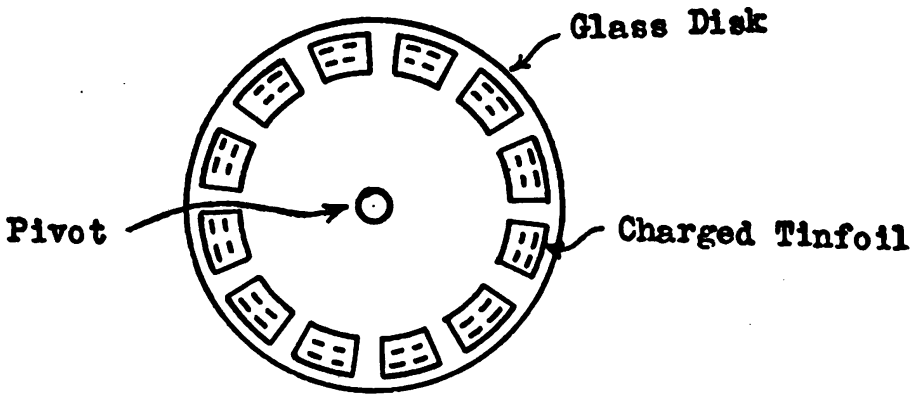


FIGURE 26.

c. An object, like the compass needle, which has a magnetic field about it is called a magnet and is said to be magnetized. Only a very few materials such as iron, steel, and nickel can be magnetized.

41. Producing magnetic field.—*a.* A magnetic field always accompanies the motion of an electric charge. The motion of the charge can be considered as the cause and the resulting magnetic field as the effect. This can be verified by the following experiment: Suppose a round glass disk with pieces of tinfoil fastened to its outer edge is rotated after the pieces of tinfoil have been charged with static electricity. (See fig. 26.)

If a magnetic compass is held above these rotating charges, it will be deflected. This shows that a magnetic field has been produced. One theory is that it is not the motion of the charge that produced the magnetic field but the motion of the dielectric field which, as has already been shown, exists in the space about charged objects. In other words, if the dielectric field could be moved, there

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would be a magnetic field produced about the path along which the motion took place. This action is reversible—that is, the motion of the magnetic field will produce a dielectric field. This will be discussed in connection with induced voltages.

b. The force of the magnetic field acts at a right angle to the dielectric field and also at a right angle to the direction in which the charge is moving. This can be visualized by imagining the magnetic force to act along concentric circles which lie in a plane perpendicular to the motion of the charge.

c. To produce a magnetic field it is merely necessary to cause a dielectric field to move or to cause an electrical charge to move. The easiest way to get charges to move is to cause an electric current to flow in a conductor. A magnetic field will be established about all current-carrying conductors. This can be verified by exploring the space about the conductor with a compass.

d. Since electrons in all materials are in constant motion revolving about the protons, there must be magnetic forces present down inside the atoms of all substances. This is true, but in most substances the magnetic field which the rotation of one electron tends to establish is cancelled by another electron rotating in the opposite direction. For this reason the atoms or molecules of most materials do not have an external magnetic field about them due to the motion of their electrons. These substances cannot be magnetized. The materials which can be magnetized must have a majority of the electron motion in one general direction such as to establish a magnetic field external to the atoms or molecules of the substance. In other words, since it has been shown that the atoms or molecules of certain substances are tiny magnets, in order to magnetize the whole object it is merely necessary to line up these atoms or molecules in such a way as to aid each other.

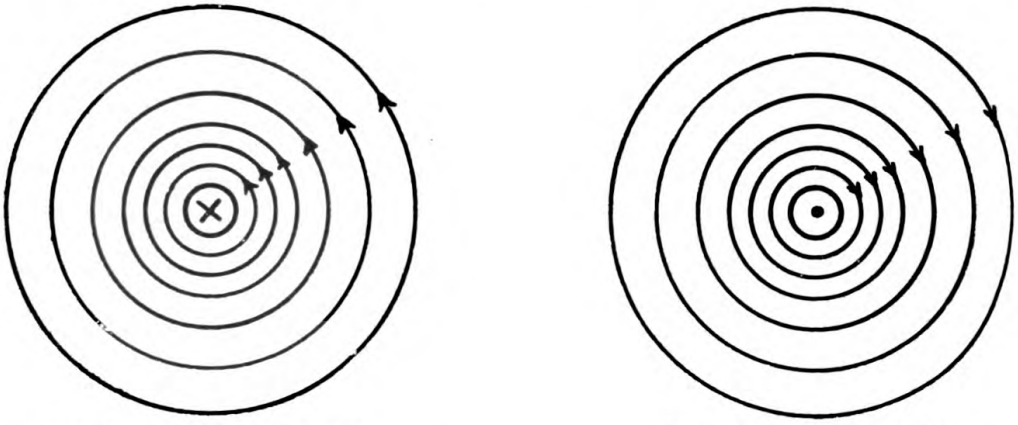
42. Representing magnetic field.—*a.* A magnetic field, like a dielectric field, is represented by lines of force. In the case of a magnetic field the lines of force are closed loops. The direction of the field is indicated by an arrowhead and the field strength or intensity by the concentration of the lines of force.

b. Figure 27 shows the magnetic field about a current-carrying conductor. Note the direction of the field and also the relative intensity near the conductor and at a greater distance from the conductor. Figure 28 shows the magnetic field about a bar magnet (a piece of magnetized steel or alloy). The dotted lines indicate that the field continues through the magnet and is really a closed loop. Notice that the lines of force radiate from the ends of the magnet and the general

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shape of the field is somewhat similar to the dielectric field between two unlike charges (fig. 4).

43. Magnetic poles.—The regions where the lines of force are most concentrated at the ends of the magnet are referred to as the



① Electrons entering paper. ② Electrons leaving paper.

FIGURE 27.—Magnetic field about a current-carrying conductor.

north and south poles (originally referred to as north seeking pole and south seeking pole, respectively). They are marked N and S in figure 28. If a magnet is suspended so that it is free to rotate (a compass needle is a magnet), one pole will point to the north and the other pole will point to the south.

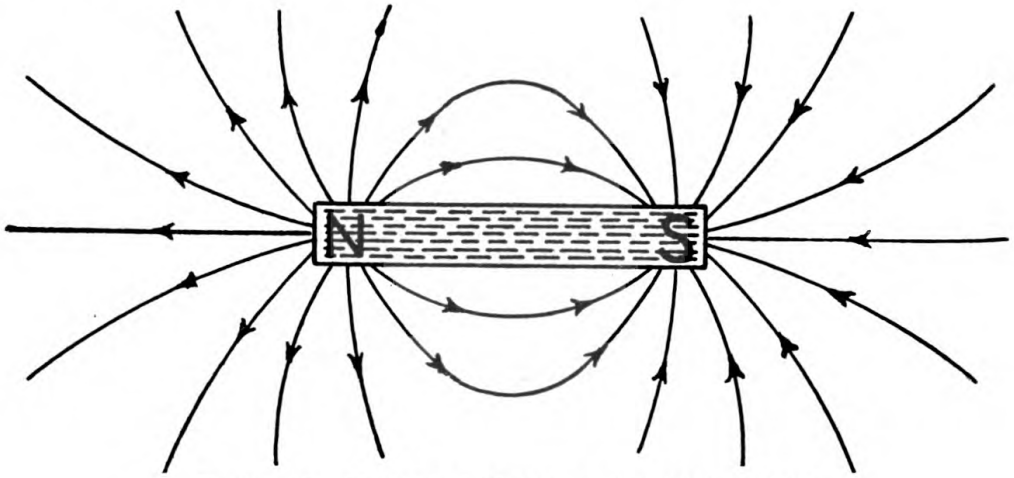


FIGURE 28.—Magnetic field about a permanent magnet.

44. Attraction and repulsion of magnetic poles.—*a.* It can be verified experimentally that like magnetic poles repel and unlike magnetic poles attract each other with a force that is directly propor-

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tional to the product of the pole strengths and inversely proportional to the square of the distance between them. This can be expressed as

$$F = \frac{mm^1}{d^2}$$

where F is the force, m and m^1 are the individual pole strengths, and d is the distance between them.

b. All of the fundamental electrical units may be derived using the above formula as a base. The results are the same as obtained by using the formula

$$F = \frac{gg^1}{d^2}$$

as the base. This is another proof that a dielectric field and a magnetic field are different forms of the same thing. Each represents a certain amount of stored electrical energy.

45. Direction of magnetic field.—*a.* The direction of the magnetic fields shown in figures 27 and 28 is indicated by arrow heads. A test object for determining the direction of a magnetic field could either be a small north pole or a small south pole. The direction of a magnetic field is taken as the direction a small north pole tends to move when placed in the field.

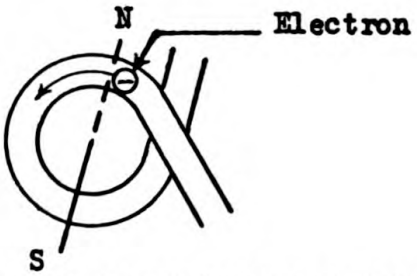
b. It is impossible to get an isolated north pole for if a north pole were cut from the end of a magnet there would appear a new south pole. The reason for this is that the magnetic lines of force are closed loops and a pole is the region where magnetic lines enter or leave a magnet. For this reason a small compass is used to test the direction of a magnetic field; the north pole of the compass points in the direction of the field.

c. Sometimes it is desirable to determine the direction of a magnetic field merely by considering the direction of the current flow in the conductor or coil that is producing the field. For determiing the direction in cases like this, several rules have been developed. One rule is that if the electrons are flowing toward the observer, the magnetic field will be clockwise. Other rules which make use of the human hand have been developed. Of course, when these rules are used it is necessary to take particular care as to whether electron flow or the conventional plus to minus current flow is being used. If the thumb of the left hand is pointed in the direction that the electrons are moving, the fingers will encircle the conductor in the some direction as the magnetic field. On the other hand, if the conventional plus to minus current is considered, the right hand must be used. The student should check each of these hand rules against the clockwise rule which was stated before.

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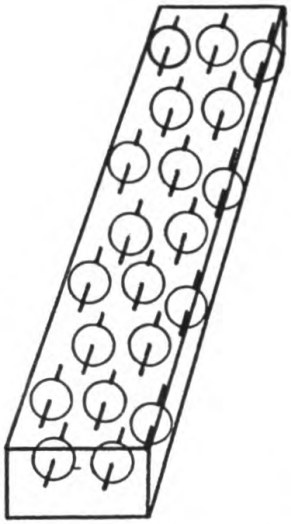
46. Permanent magnets.—*a.* A permanent magnet is an object (usually a piece of steel or alloy) which has a magnetic field about it without applying an external magnetizing force to sustain the field. The word "permanent" is used to distinguish this type of magnet from a temporary magnet which will be taken up later.

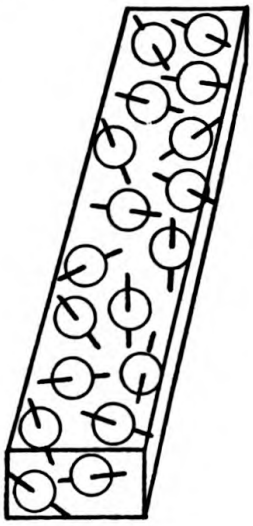
b. It has been shown that magnetic lines of force are always closed loops. In the case of a permanent magnet the lines of force pass through the interior of the magnet.



① Magnetic effect of an electron in a single turn of wire.







② Magnetic effect of electron rotating in its orbit.

③ Magnetized body.

④ Unmagnetized body.

FIGURE 29.

c. The electron theory of magnetism explains the field in a permanent magnet by showing that it originates in the atoms of the iron and not in the poles of the magnet. The poles are merely the points at which the lines of force seem to originate to any outside observer.

d. If an electron be made to pass around a single turn of wire, a magnetic field will be produced by the moving dielectric field associated with the electron. Since the magnetic lines of force are closed loops, all of them have to pass through the interior of the

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single turn of wire. This gives a strong field in this region, and the single turn of wire acts as a magnet with poles as shown in figure 29 ①.

e. An atom of any substance consists of electrons rotating about a center nucleus. The electrons rotating in the closed loop of figure 29 ① give the effect of a magnet, therefore each electron rotating in its orbit about the nucleus of an atom also acts as a tiny magnet. This is shown in figure 29 ②.

f. If, for the moment, it is considered that each atom consists of a nucleus and a single electron in an orbit, it is seen that an arrangement of the axes of rotation of these electrons as shown in figure 29 ③ will give the external effect that is associated with a magnet, since the fields produced by all the individual rotating electrons will be additive. If the atoms are arranged as in figure 29 ④, however, the fields produced will nullify each other and there will be no external effect.

g. In actual atoms there are a number of electrons rotating in fixed orbits relative to the nucleus and to each other. The axes of these orbits are arranged at various angles to each other, depending upon the type of substance. There is a large probability that the resultant field of all the electrons rotating about various axes will be zero or nearly so. An atom that has no magnetic field produced within itself will not be acted upon by an external field, and hence a substance made up of atoms of this type is nonmagnetic. A substance made up of atoms having a weak resultant field is slightly affected by an external field and is classed as a paramagnetic substance.

h. In the atoms of some substances a larger number of electrons rotate in one direction than in others and a relatively large field is produced by such an atom. This atom tends to line itself up with an external field and in so doing adds its field to that of the external field. Thus the atoms of a piece of soft iron line up with any field in which they are placed and increase the effect of the field. When the soft iron is removed from this field, most of the atoms return to their original positions, leaving the iron but slightly magnetized. This slight magnetism is referred to as residual magnetism. If a piece of steel had been used, the strength of the field would not have been increased to such a large extent as with the soft iron. Not as many atoms would have been turned around because of the high internal frictional forces between them. However, when the steel is removed from the field, most of the atoms that were turned around stay lined up and a permanent magnet is the result. Practically all permanent magnets are made in this manner.

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i. There are several types of permanent magnets in general use. They are classified as to their shape and also as to the material used. The straight magnet is usually called a bar magnet. If the magnet is in the shape of a horseshoe or the letter **U**, it is usually referred to as a horseshoe magnet. As was mentioned above, soft iron cannot be used for permanent magnets. The materials usually used are either hard steel or some alloy of steel. The strongest permanent magnets at the present time are made from alloys of aluminum, nickel, and cobalt and are called "alnico." They are very much stronger than the ordinary steel magnets. Cobalt chromium alloys make very good permanent magnets. (See fig. 30.)

47. Electromagnets or temporary magnets.—*a.* It was shown above that a piece of soft iron when placed in a magnetic field becomes a magnet, but when the external field is removed the iron loses practically all of its magnetism. This principle is used in the electromagnet or temporary magnet. The combination of a coil of wire with a core of soft iron which is made a magnet by the passage of current through the coil is an electromagnet or temporary magnet. (See fig. 31.)

b. Figure 32 shows how the fields about the individual turns add up to give the resultant field about a coil of wire.

c. Electromagnets can be made much more powerful than the strongest permanent magnets. Even as early as 1831 Joseph Henry constructed an electromagnet whose iron core weighed less than 60 pounds yet could support over a ton. The strength of an electromagnet is determined mainly by the number of turns on the coil, the amperes of current, and the kind and amount of iron in the core. The size, shape, and mechanical arrangement of the core have a definite bearing on the magnet's strength.

48. Solenoids.—The word "solenoid" as used in electricity has several meanings. Strictly speaking, the solenoid is a tubular coil for the production of a magnetic field. Many times a long, narrow coil of wire with or without a core is referred to as a solenoid. In manufacturing circles, the solenoid is a special kind of electromagnet whose core, or part of it, is free to move. The magnetic field tends to pull the core into the coil when the current is turned on. This gives a relatively long uniform pull for actuating, by remote control, many mechanical devices.

49. Polarity of electromagnets.—The polarity of electromagnets or solenoids may be obtained by testing with a compass or by applying a simple rule. If the coil is grasped in the left hand so that the fingers follow around the coil in the direction in which the electrons

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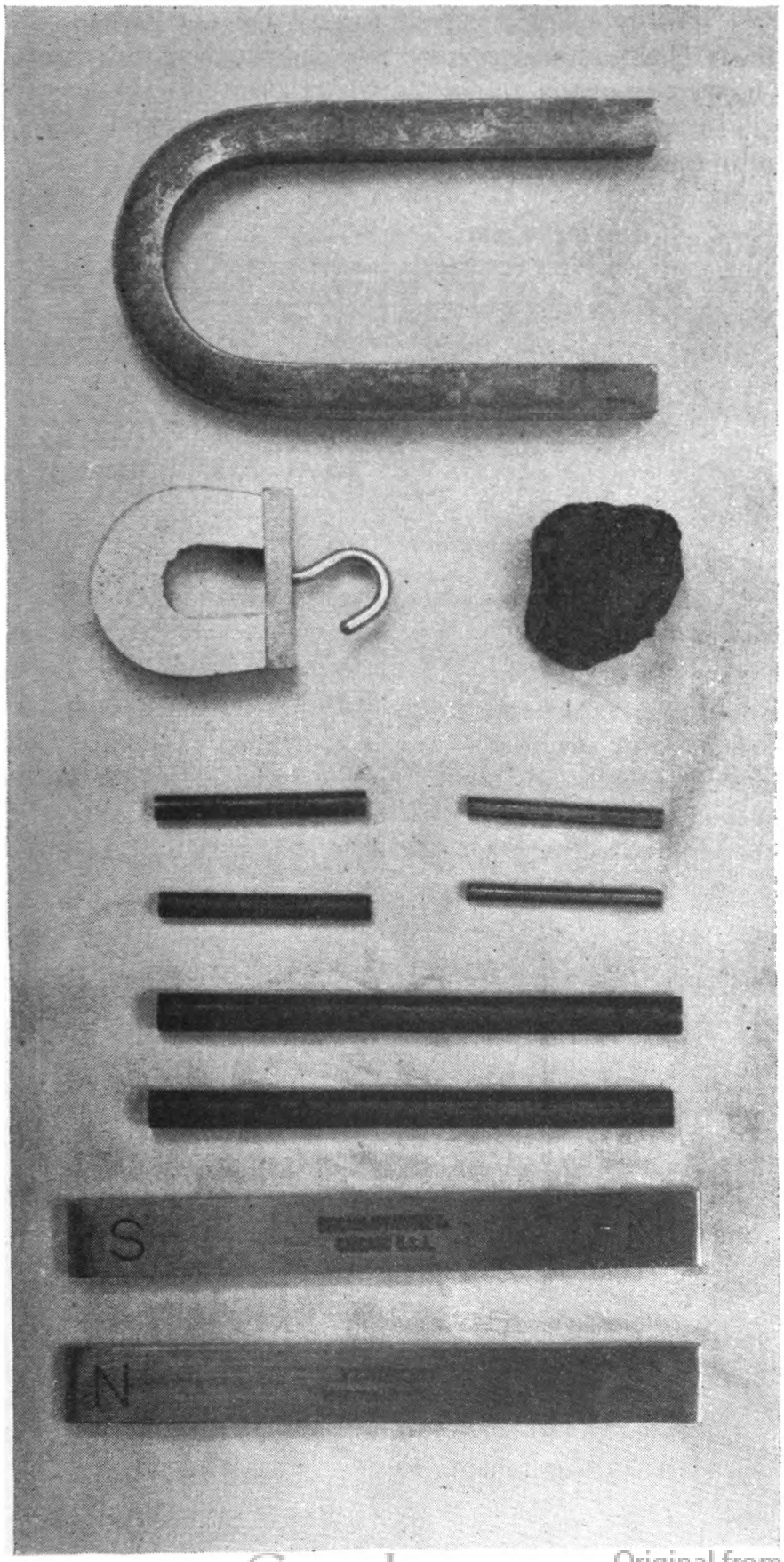


FIGURE 30.—Various types of magnets.

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are flowing, the thumb will extend toward the north pole. If the conventional plus-to-minus current is assumed, then the right hand must be used to determine the north pole of a coil. In this case, when the fingers encircle the coil in the direction of the current, the thumb will point to the north pole of the coil.

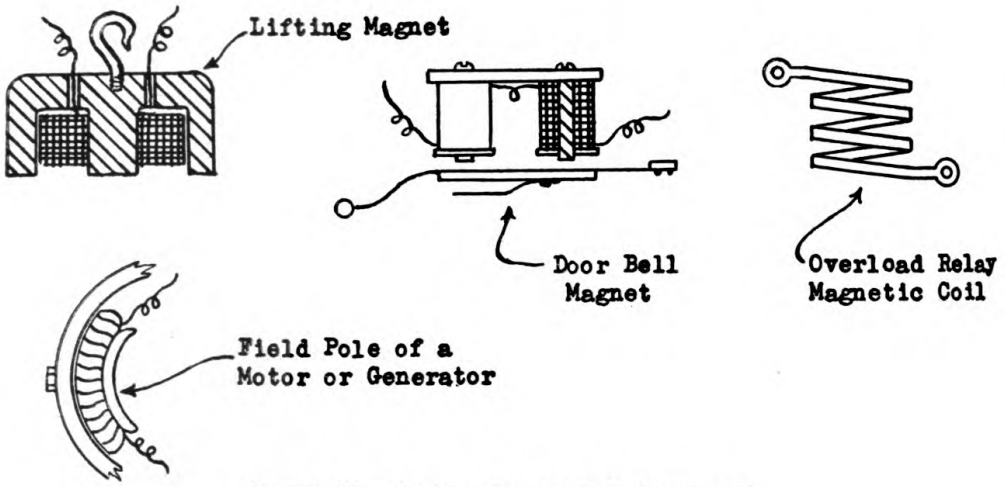


FIGURE 31.—Various forms of electromagnets.

50. Resultant magnetic fields.—Magnetic fields react on each other in such a way as either to aid or neutralize. If magnetic fields from different sources are occupying the same region or space, the resultant field will be stronger provided the individual lines of force are in the same direction. On the other hand, if the lines of force

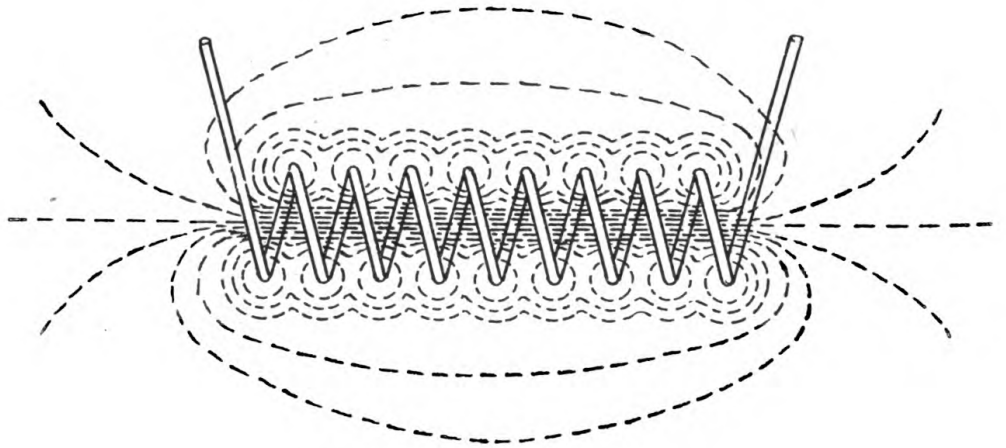


FIGURE 32.

from the two sources are in opposite directions, the field will be weakened. The resultant fields and the effects of distorted field shapes shown in the following figures are important in studying and analyzing certain electrical equipment.

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a. Figure 33 shows the resultant field about two permanent magnets with the opposite poles adjacent.

b. Figure 34 shows the resultant fields about two permanent bar magnets with the like poles adjacent.

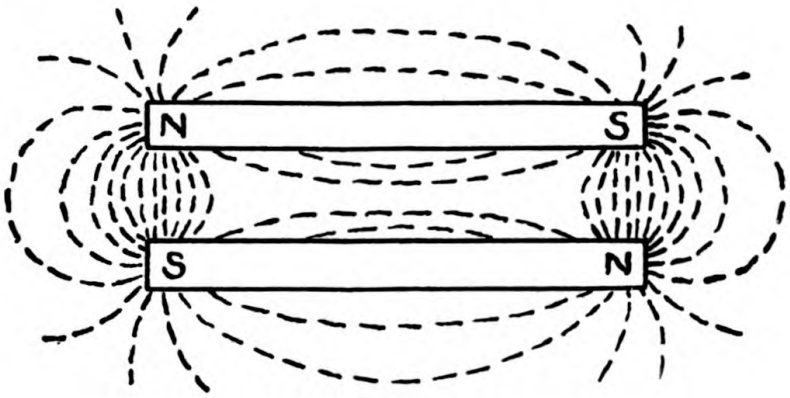


FIGURE 33.

c. Figure 35 shows the distorting effect of a piece of soft iron placed in a magnetic field.

d. Figure 36 shows the distorting effect of a current-carrying conductor placed in a magnetic field.

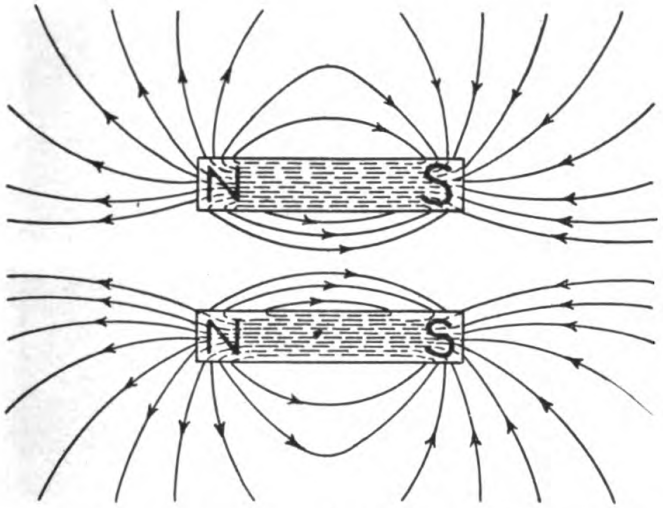


FIGURE 34.—Resultant field about two bar magnets.

e. Figure 37 illustrates how magnetic field patterns may be obtained by the use of iron filings.

51. Magnetic units.—*a.* A series of units have been developed for magnetism which in certain instances have a similarity to the units which were developed for electrical potential, current, and resistance. Magnetomotive force is the unit which corresponds to electromotive

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force. Flux is the name given to the magnetic unit which corresponds to the electric current. Reluctance is the magnetic unit which corresponds to electrical resistance. In other words, it takes a magnetomotive force to establish flux in a magnetic circuit. Also the amount of flux that will be established for a certain magnetomotive force depends

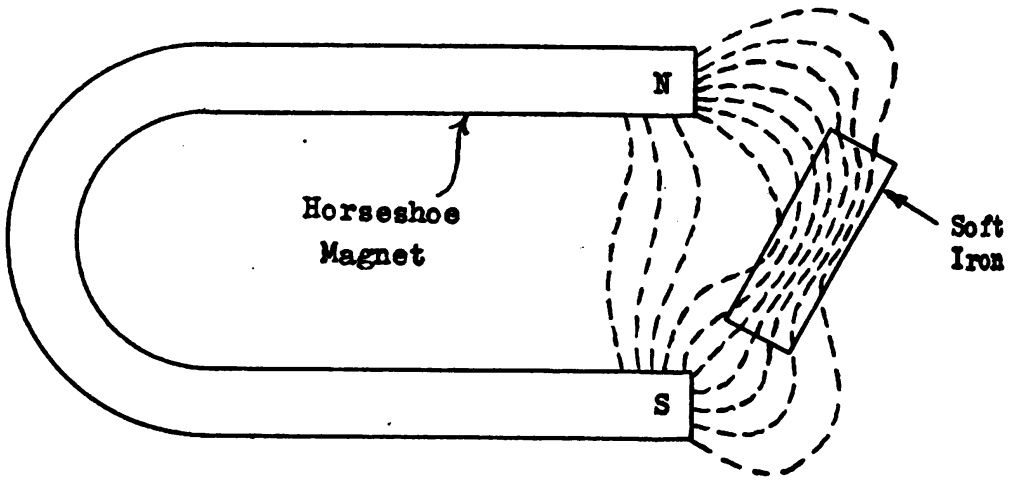


FIGURE 35.

on the reluctance of the magnetic circuit. There is a definite relation between these magnetic units. This relation is very similar to the relation between the corresponding electrical units. A so-called Ohm's law can be written for magnetism; that is, flux equals magnetomotive force divided by reluctance.

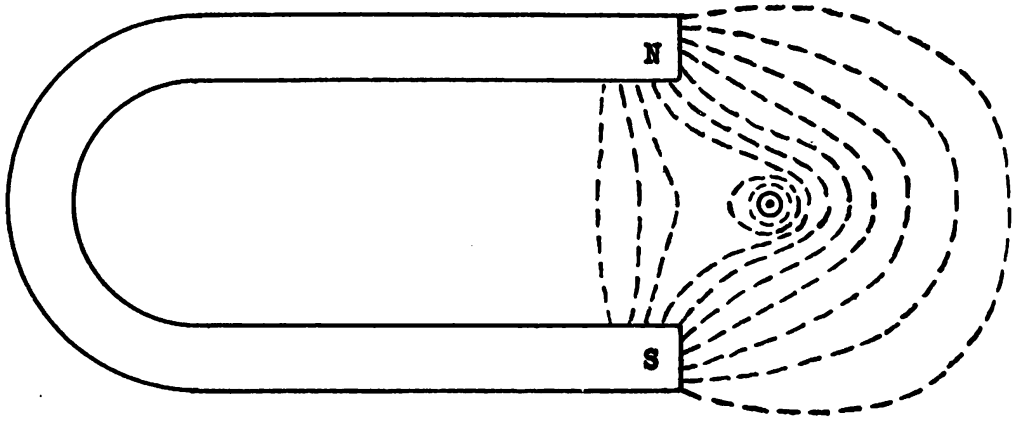


FIGURE 36.

b. Practically, except in the case of permanent magnets, magnetic effects are produced by current flowing in a coil made up of a number of turns of wire. The magnetic effect of a coil is proportional to the current flowing in it, and since each turn adds its magnetic effect to that of all the other turns, this magnetic effect is also proportional to the

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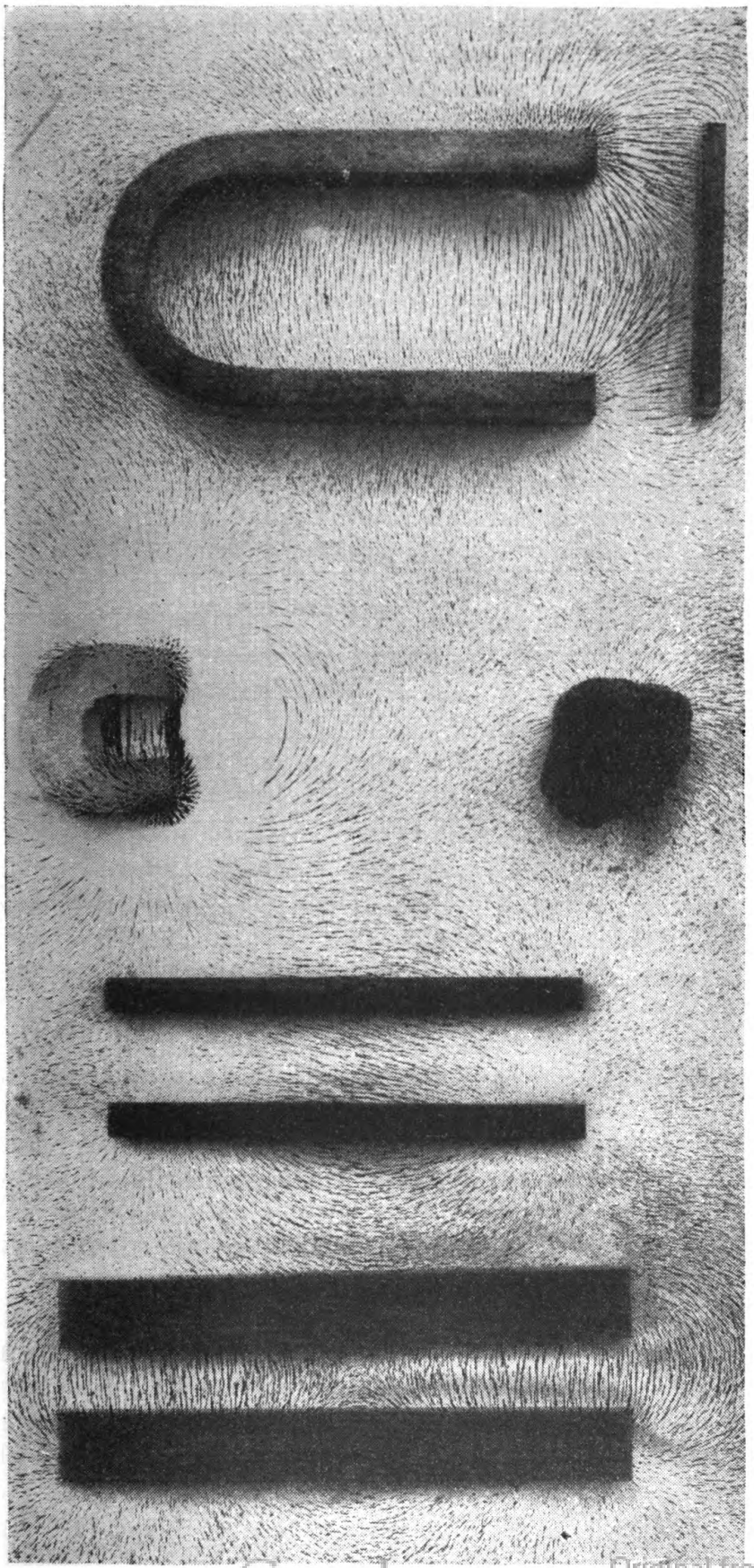


FIGURE 37.

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number of turns. Hence, magnetomotive force (m. m. f.) is often expressed in ampere turns or $I \times T$.

c. Reluctance is the opposite of flux and, as was stated above, corresponds to resistance in an electric circuit.

d. Permeability is the reciprocal of reluctance. Permeability is used more often in explaining the properties of a magnetic circuit than is reluctance. The symbol for permeability is μ. Thus $\mu = 1/\text{reluctance}$ or $\text{reluctance} = 1/\mu$.

e. If we transpose the law for a magnetic circuit we get flux= M. M. F. $\times \mu$. The permeability of nonmagetic substances is one while

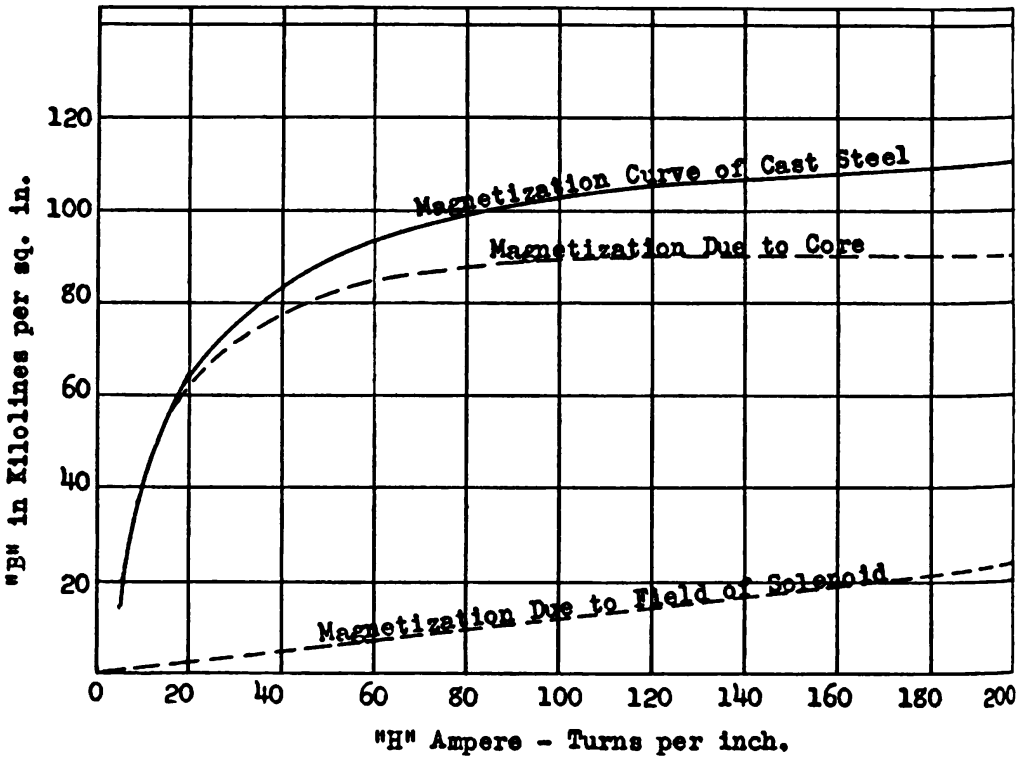


FIGURE 38.

all magnetic substances have a permeability greater than one. It is seen that of two magnetic substances the one with the higher permeability will increase the flux produced to a greater extent. This is usually shown graphically by plotting magnetization curves for the various magnetic substances.

52. Magnetization curve.—*a.* In considering the magnetic properties of iron, steel, and alloys, magnetization curves are made use of. Instead of making use entirely of the Ohm's law for magnetism, it is easier in many cases to obtain the desired information from a graph. This magnetization graph usually has ampere turns per inch plotted

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against flux density. As was stated above, ampere turns can be used as a unit for magnetomotive force. Since it is not the total magnetomotive force that is of interest, the force per unit length of the material under test is plotted. Also, it is not the total flux that is of importance; instead, it is the flux density or, in other words, the number of lines of force per square inch. For this reason magnetization curves for various samples of material will give the same information regardless of the size of the sample which was actually used in obtaining the data for the magnetization curve. Figure 38 shows a typical magnetization curve of cast steel.

b. H is the symbol used for ampere turns per inch and B is the symbol used for flux density. Many times these curves are referred to as BH curves. Along with this magnetization curve is shown the field or magnetization that would be produced by the solenoid furnishing the magnetizing force if the steel core were not present. The magnetization curve less the field due to the solenoid, then, gives the magnetization due to the core alone. It is seen that along the lower part of the curve most of the increase in magnetization is due to the steel, but when the magnetizing force exceeds 100-ampere turns per inch the magnetization of the steel does not increase; it has reached saturation.

c. When all the electron orbits of a magnetic material have been turned around by the magnetizing force, the material is saturated, and an increase of applied magnetizing force does not result in noticeable increase of magnetism. Examination of the curve of figure 38 shows that up to about 20-ampere turns per inch, a large number of lines of force are produced per ampere turn, more than 3,000 lines. Increasing H from 20-ampere turns per inch to 40-ampere turns per inch produces an increase of 20,000 lines per square inch or only 1,000 per ampere turn. Increasing H from 40 to 80 increases B by about 12,000 lines or 300 lines per ampere turn. From 80-ampere turns per inch to 200-ampere turns, the increase is only a little more than 100 lines per ampere turn. The nearer the BH curve approaches a vertical line, the greater is the number of lines of force produced by a given number of ampere turns. The point where it begins to flatten out is called the "knee" of the magnetization curve. Good design dictates that the cross-sectional area of the magnetic circuit should be ample, so that the density of the flux in the magnetic material is not very much above the knee of the curve. In radio circuits it is usually desirable that the flux density remain below the knee.

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SECTION V

ALTERNATING CURRENT

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53. General.—*a.* So far, continuous current phenomena only have been considered; that is, the current was always uniform and in the same direction. Current of this nature is usually referred to as direct current (d. c.).

b. Even in d. c. circuits the current must start from zero and build up to the final value when a switch is closed and die down to zero when the switch is opened. These are only momentary variations and are neglected when dealing with and developing the rules and formulas for d. c. circuits.

c. As was stated in connection with magnetism, a motion of a magnetic field produces a dielectric field. Also it has been shown that a dielectric field of force represents a potential or voltage. Hence, the motion of the magnetic field can produce a voltage. This can be experimentally verified by moving a permanent magnet so that the flux cuts across a conductor whose ends are connected to a galvanometer (a device for indicating voltage or current). A very sensitive instrument must be employed if only one wire is used. To get a noticeable effect on an ordinary laboratory galvanometer, a coil of wire should be used so that the e. m. f. produced in each turn of the coil will be additive. To get this result the magnet should be thrust into the end of the coil. (See fig. 39.)

d. Voltage produced in this manner is referred to as induced voltage. As was mentioned above, when a switch in a circuit is opened or closed the current rises to its full value or diminishes to zero. Since current produces a magnetic field, then the magnetic field must build up and collapse when the switch is opened and closed. (See fig. 40.) Since an expanding or collapsing magnetic field is a moving magnetic field there must be a voltage produced each time the switch is opened

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or closed. This voltage will act on the circuit itself or on any other circuit situated in the moving magnetic field. These voltages are induced voltages.

e. Alternating current (a. c.) is defined as current which continually changes in magnitude and periodically reverses in direction. In other

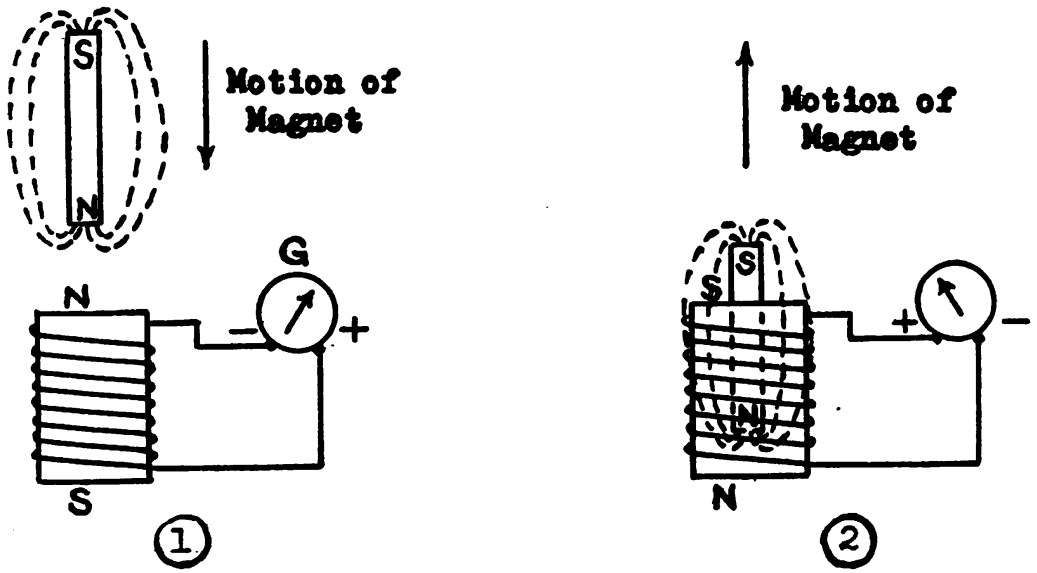
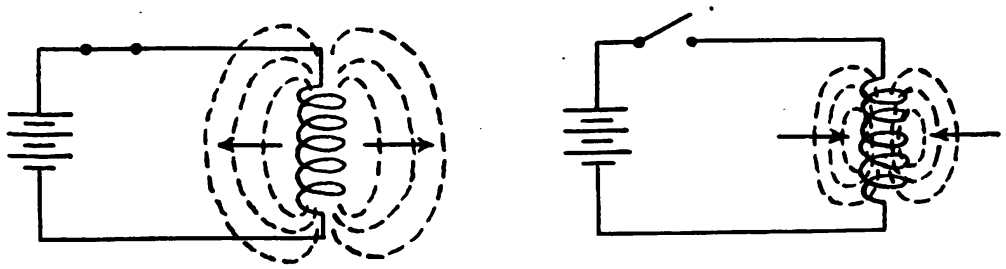


FIGURE 39.—Inducing e. m. f. and current in conductor by means of magnetic field.

words, the current is repeatedly building up from zero to a final value in one direction, dying down to zero and then building up in the opposite direction, and dying down to zero again. It can be seen from the definition that the momentary effects of opening and closing switches in d. c. circuits will be continually taking place in a. c. circuits.



① When switch is closed field moves out. ② When switch is opened field moves in.

FIGURE 40.

f. Since induced voltages will always be present in a. c. circuits in addition to the applied voltage, special rules and formulas must be used. In general, the laws developed for d. c. still apply to a. c. if certain modifications are made; that is, the general ideas embodied in Ohm's and Kirchoff's laws can still be used, but with different formulas.

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54. Generating alternating e. m. f.—*a.* One way to generate an alternating e. m. f. is to move a magnet in and out of a coil. From previous explanations it can be seen that a continually varying and periodically reversing voltage would be induced. This is not practical, however, and is never used as a commercial method for generating alternating current.

b. In order to induce voltage an actual motion of the magnetic field is not necessary. A relative motion of the conductor and the field is all that is required. In other words, if the magnet in figure 39 were left still and the coil moved, the voltage would be induced just the same. Many electrical generators make use of this principle.

c. The above principle is used in the electric generator shown in simple form in figure 41. Here, a single loop of wire *A–B–C–D* is arranged to be mechanically rotated on a shaft between the poles N and S of two powerful electromagnets. It will be assumed that the magnetic field between the poles is uniform, as shown; that is, of the same strength throughout. The two ends of the coil are connected to two collector rings (of brass or copper), *F* and *G*, respectively, which are insulated from each other and from the shaft. They are arranged to rotate with the coil. The two stationary copper or carbon brushes *H* and *J* make a wiping contact with these rotating collector rings to lead the current to the external circuit, consisting in this case of lamp *L*. This arrangement of parts, not including the external circuit, constitutes the simplest form of a. c. generator.

d. Let it be assumed that the coil starts from the vertical position shown in figure 41 ① and rotates at a uniform speed in a clockwise direction. At the initial position, the induced e. m. f. is zero because the inductors *A–B* and *C–D* are moving parallel to the lines of force and therefore not cutting any. That is, in a given small angular movement from this position there will be very few lines of force linking with the loop and hence very little e. m. f. will be induced.

e. It should be noted that at the initial position all the lines of force of the field are passing through the loop, but this does not mean an e. m. f. is induced. The induced e. m. f. is proportional to the rate at which the inductors cut the lines of force and hence to the rate of change of the lines of force linking or unlinking with the loop, and not to the total number of lines of force through the loop. For instance, when a bar magnet was held stationary inside a solenoid, no e. m. f. was induced in the coil even though all the lines of force of the magnet went through the solenoid in this position.

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When the magnet was moved so as to link or unlink lines of force with the coil, an e. m. f. was induced.

f. As the coil moves away from the vertical position, lines of force begin to unlink with the loop at an increasing rate and hence the induced e. m. f. becomes larger and larger. At the horizontal position, figure 41 ②, the coil has the maximum e. m. f. induced in it, because during a small angular movement from this position the

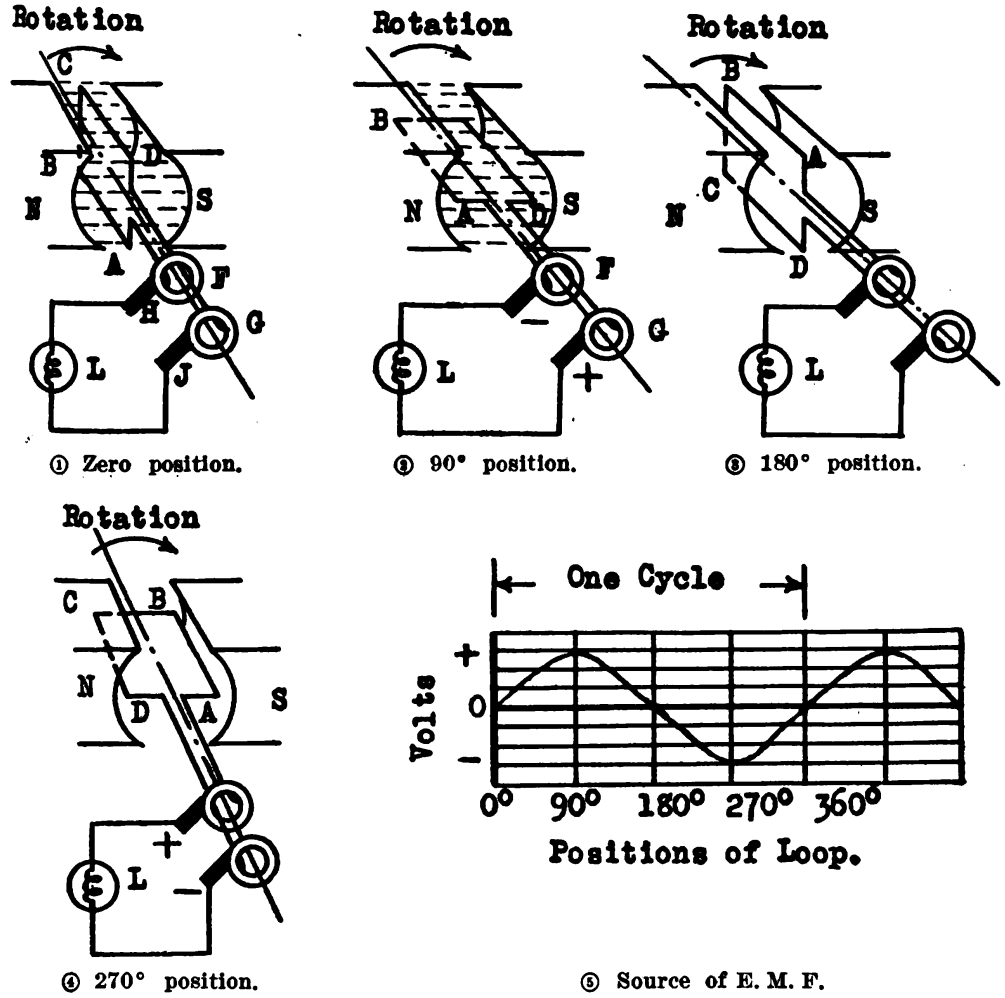


FIGURE 41.—Generator on alternating e. m. f.

maximum number of lines of force are cut per second by the inductors *A–B* and *C–D* because they are moving at right angles to the field.

g. As the coil continues on to the vertical position of figure 41 ③, the e. m. f. is still in the same direction but diminishes in value until at the vertical position it is again zero. As it continues past this point, the induced e. m. f. changes in direction. The e. m. f. increases in strength and becomes a maximum when the coil is hori-

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zontal. Continuing the rotation another 90° brings the coil back to its original starting position and condition. The e. m. f. decreases to zero again. As the rotation is continued, the above conditions repeat themselves over and over.

h. The voltage induced in the coil at any instant may be plotted against the angle through which the coil has rotated from the zero position. The resulting curve is shown in figure 41 ⑤. When the voltage is induced in one direction, it is called positive and is laid off above the zero axis. When it is in the opposite direction, it is called negative and is laid off below the zero axis.

Angle---	0	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°	360°
Sine----	0	.50	.866	1.00	.866	.50	0	−.50	−.866	−1.0	−.866	−.50	0

i. In one complete revolution of the coil there are two positions (fig. 41 ① and ③), at which there is no induced voltage and hence no current in the external circuit, and two positions (fig. 41 ② and ④), at which the voltage is at maximum value although in opposite directions. At intermediate positions the voltage has intermediate values. A complete revolution of the coil takes 360° of rotation.

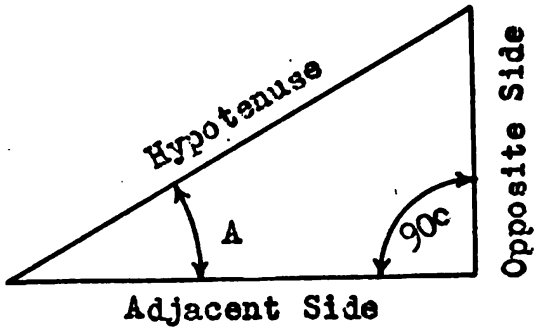


FIGURE 42.

55. Representing a. c. voltage and current with sine curve.— *a.* Any phenomena can be represented graphically. In the case of a. c. it is very convenient to use this method, for most alternating voltages and currents can be represented by a simple sine curve.

b. The sine of an angle is one of its trigonometric functions and can be represented very simply in terms of the sides of a right triangle. Referring to figure 42, the sine of angle *A* is equal to the opposite side divided by the hypotenuse. The value of the sine for any angle can be found in tabulated form. The following table gives the sine of angles from 0° to 360° in 30° steps.

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c. Figure 43 shows the sine of an angle plotted against degrees. This is known as the sine curve. Study this sine curve carefully and compare it with the graph of the simple one coil generator's output shown in figure 41 ⑤.

56. Frequency.—*a.* In any reoccurring periodic phenomena, frequency is the term used to represent the number of complete reoccurrences which take place in unit time. The time taken for one reoccurrence is termed the period, and the cycle is a term used to represent one complete set of the reoccurring phenomena.

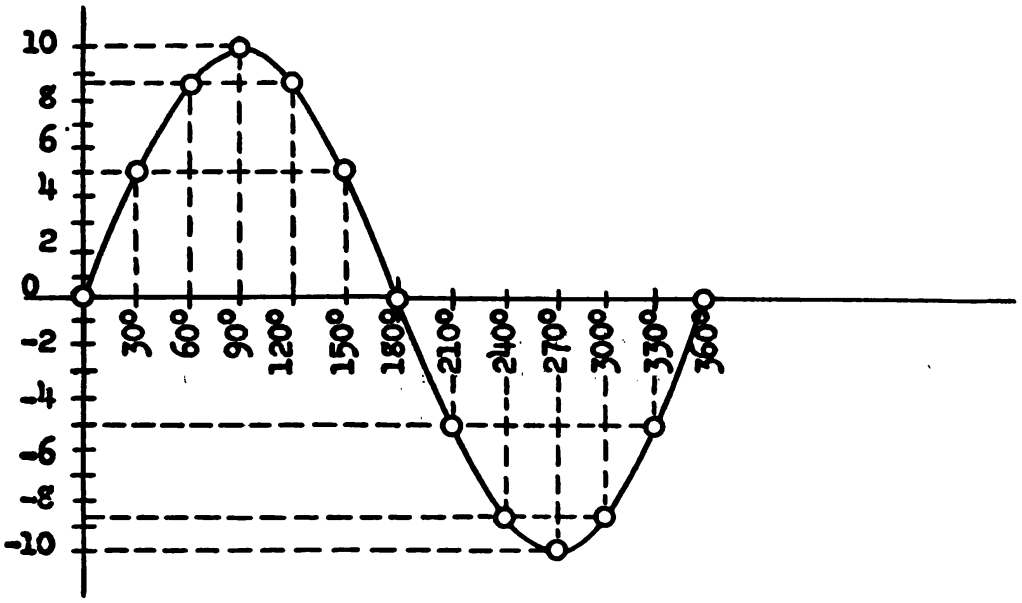


FIGURE 43.—Sine curve.

b. In considering alternating current and voltage, these terms are used many times. The term "alternation," which represents one-half of a cycle, is also used.

c. The symbol used to represent frequency is f, and the units used for frequency are the cycle per second, kilocycle per second, or megacycle per second. If the period is represented by T then—

$$T=\frac{1}{f}$$

d. For a frequency of 60 cycles per second the period would be $\frac{1}{60}$ second. Since it requires 1 second to complete 60 cycles, it requires but $\frac{1}{60}$ second to complete 1 cycle.

e. A. c. current and voltage can be shown graphically by plotting the value of current or voltage against time instead of degrees. (See fig. 44.) Compare figures 43 and 44 and notice that the end of a cycle is represented by a time interval equal to the period.

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57. Maximum value of e. m. f. and current.—As has been shown, alternating voltage and current are continually varying in magnitude. In other words, the instantaneous values are changing. These instantaneous values can be obtained from the sine curve of voltage or current, but the only ones that are used to any great extent are the maximum or instantaneous peak values. As has already been shown, a maximum or peak value occurs twice for each cycle. There is a positive maximum and a negative maximum value. It will be shown later how this maximum or peak value of current or voltage can be used to determine the average and effective values which are used in the solution of a. c. problems.

58. Average value.—As can be determined by observing the sine curve of alternating current or voltage, the true average value for a

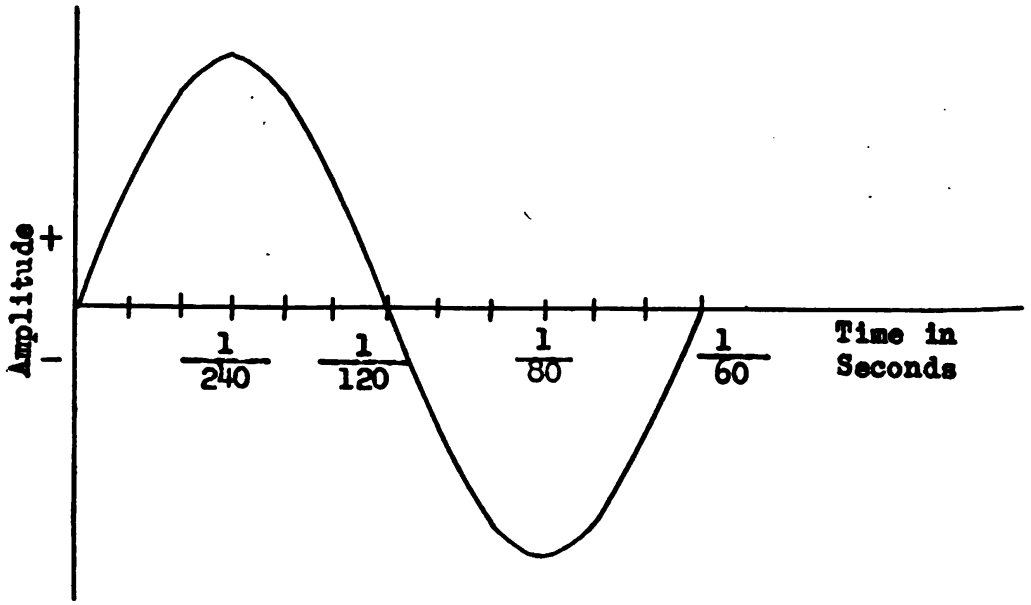


FIGURE 44.

full cycle is zero because there is just as much above the zero axis as there is below it. When using average values in connection with alternating current or voltage it is not the average of the full cycle that is usually meant. Instead it is the average for one-half cycle or one alternation. To get the average it is merely necessary to add up a number of the instantaneous values and divide by the number taken. The more values used in obtaining the average the more accurate the result will be. By a higher mathematical process an infinite number of instantaneous values can be averaged. By this method it is found that the average value of one-half cycle of a sine curve is equal to .636 times the maximum or peak value. In other words $I_{ave.} = .636\ I_{max.}$

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Also, $E_{ave.} = .636\ E_{max.}$ This relation of the average and maximum values is important in the solution of certain a. c. problems.

59. Effective or R. M. S. value.—*a.* The value of alternating current and voltage which is ordinarily used in practice is neither the instantaneous nor the average value. To make alternating current compare as nearly to direct current as possible, it was decided to use an effective value. In other words, find the value for the sine curve of alternating current or voltage which would have the same effect in producing power as a corresponding direct current value. At first it might seem that the average value would do this, but if the two formulas for power, that is, $W = I^2R$ and $W = \frac{E^2}{R}$ are considered it can be seen that power is proportional to the square of the current or the square of the voltage. This means that the effective value must be

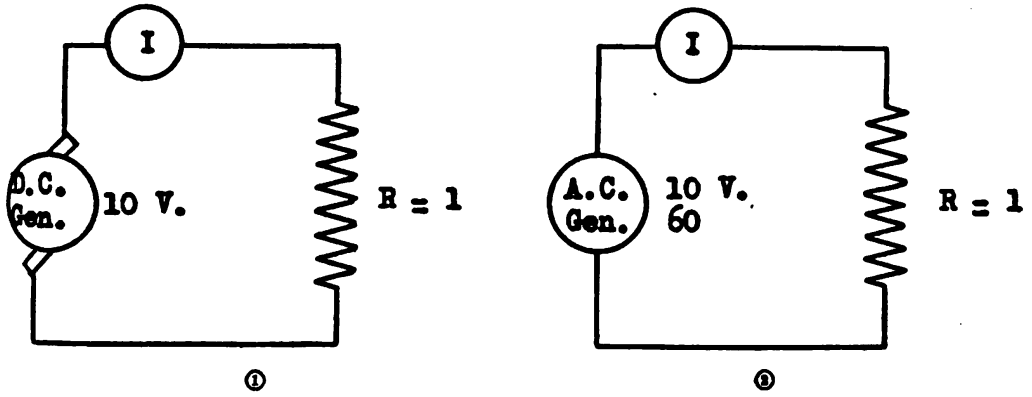


FIGURE 45.

obtained by averaging or finding the mean of the instantaneous values squared, then extracting the square root. By this method the effective value is obtained. Due to the method of obtaining this value, the abbreviation R. M. S. (root mean square) is sometimes used. The effective value of a sine curve of alternating current or voltage can be given in terms of the maximum value. The effective value is equal to .707 times the maximum or peak value. From this expression it can be determined that the peak value will be 1.41 times the effective value, and also a ratio between the effective value and average value may be determined.

b. A. c. meters are usually calibrated in effective values. This means that when an a. c. meter reads a certain voltage or current the effect as far as power is concerned will be the same as the same voltage or current in a d. c. circuit. (See fig. 45.)

c. In figure 45 ① is shown a d. c. generator furnishing power through an ammeter to a resistor, and figure 45 ② shows an a. c. gen-

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erator furnishing power to a similar resistor through an a. c. ammeter. Figure 46 shows the values of current in the above cases plotted against time.

d. Of course, in the case of d. c. the current graph will merely be a horizontal line, while in the case of the a. c. the current will be shown by a sine curve. In each case the meter reads 10 amperes and, as was shown before, the effect as far as power is concerned is the same. On the other hand, the graphs show that in the case of the d. c. circuit the 10 amperes are flowing all the time and in only one direction. On the other hand the sine curve of a. c. shows that the current is continually changing in magnitude and periodically reversing in direction. In order for this current to have the same effect as 10 amperes which are flowing all the time, it can easily be seen that at certain instances there must be more than 10 amperes

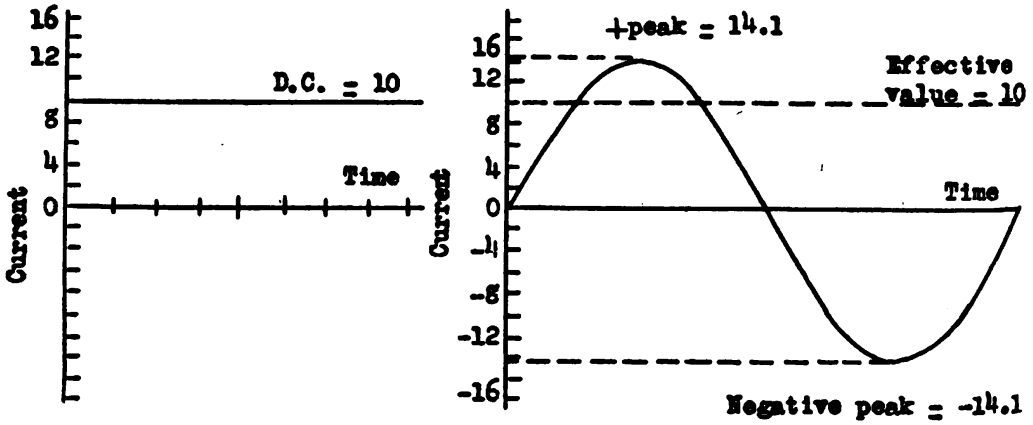


FIGURE 46.

flowing. In fact, if the graph is examined carefully, it will be seen that twice each cycle there are 14.1 amperes flowing. This could have been determined by merely applying the ratio mentioned above for the maximum and effective values (the maximum value is 1.41 times the effective value) and remembering that the a. c. meters are calibrated in effective values. Therefore, if the a. c. meter reads 10 amperes, the sine curve of a. c. current would reach twice each cycle, or 14.1 amperes.

60. Phase relations of a. c. voltage and current.—*a.* Another thing encountered when dealing with alternating current is the phase relation of the voltage and current in the circuit. If the voltage and current vary in step with each other, that is, each passing through zero and reaching its maximum value at exactly the same time, they are said to be in phase with each other. In general, the term "phase" can be defined as the fraction of a whole period

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which has elapsed since the thing in question last passed through its zero or middle position in a positive direction. In other words, if the voltage and current do not vary in step with each other, but one passes through zero or reaches its maximum value at a different

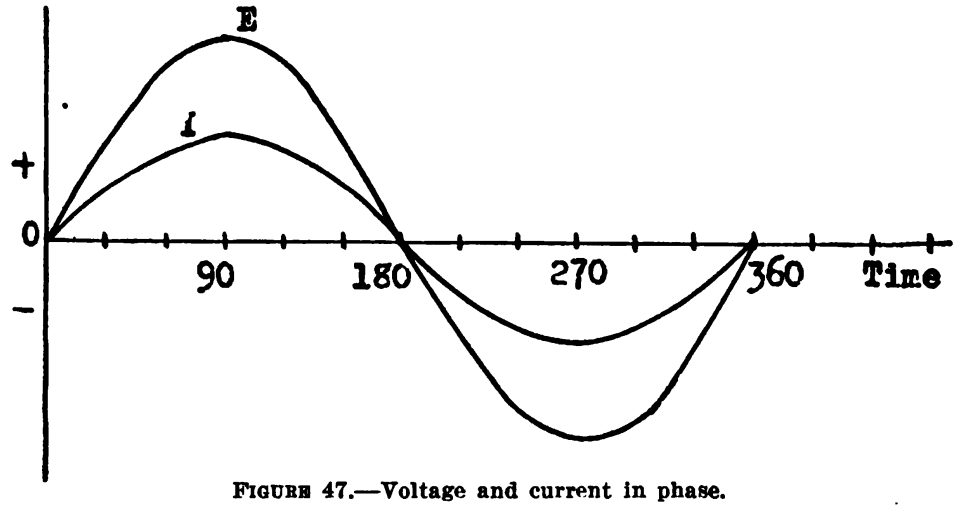


FIGURE 47.—Voltage and current in phase.

time from the other, then they are out of phase. There will be a time lag between the successive events taking place in one with respect to similar events taking place in the other. In practical cir-

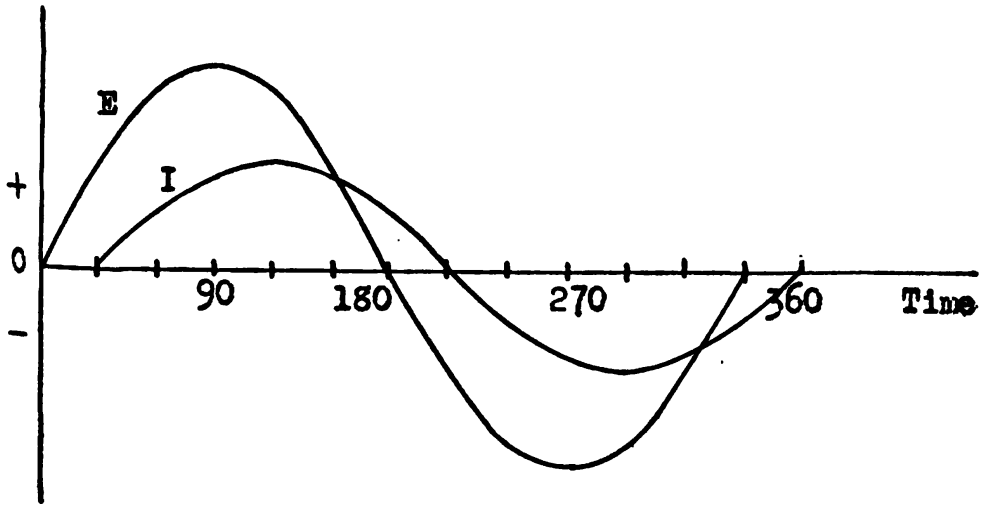


FIGURE 48.—Current and voltage out of phase.

cuits the current can either lag behind or lead the voltage. The reasons for these phase differences will be taken up later.

b. Phase relations can be illustrated by the use of sine curves. An easy way to do this is to plot both curves on one set of axes. (See figs. 47 and 48.)

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c. In figure 48 the current is shown lagging the voltage. Note that along the time axis the voltage reaches its peak first. The amount that the current lags is obtained by noticing the difference in time as read on the horizontal axis of the curve between any two corresponding points of the voltage and current curves. The easiest points to consider for determining phase difference are either the zero points or the maximum points. In this method of plotting current and voltage, that is against time, phase differences would be given in time units. Since it is the usual procedure to label the horizontal axis of a voltage or current curve in degrees, then under these conditions the phase difference would be given in so many degrees of angle. In other words, the current in the above graph is lagging the voltage by 30°. This would be referred to as a phase angle of 30°.

61. Impedance.—*a.* As was stated before, the rules and formulas for a. c. circuits must be modified. The d. c. rules and formulas will apply only for instantaneous values. In order to use effective values of voltage and current, consideration must be given to the effect of the counter voltage produced by the varying magnetic field. This voltage is in such a direction as to act like an additional opposition to the flow of alternating current.

b. The total opposition to the flow of alternating current in a circuit is called impedance. Since it is an opposition to the flow of current, it has the same unit as resistance (i. e., the ohm). The symbol used to represent impedance is Z.

62. Ohm's law for alternating current.—If R is replaced by Z in the d. c. Ohm's law, it will apply to a. c. circuits. Ohm's law for a. c. can be written as follows: $I=\frac{E}{Z}$, $E=IZ$, $Z=\frac{E}{I}$. Under the special conditions where the voltage and current are in phase, which will be the case if a pure resistance load is used, the impedance and the resistance of the circuit are identical. Under these conditions, the d. c. Ohm's law still applies to a. c. On the other hand, when the voltage and current are out of phase, the impedance is always greater than the resistance. The method for finding how much greater the impedance is for any value of phase angle will be taken up later.

63. Power in a. c. circuits.—*a.* Provided the voltage and current are in phase, the power consumed in a. c. circuits is the same as if d. c. were used. Any of the power formulas developed for direct currents will apply under the above conditions. On the other hand, if the voltage and current are out of phase with each other, the only power formula which will give the true power consumed by the circuit is I^2R. This value will be less than would be obtained by multiplying

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the effective volts and the effective amperes. The expression *EI* or volt amperes is referred to many times as the apparent power.

b. The ratio of the true power to the apparent power is called the power factor. Power factor can be considered as just a ratio or it can be considered in terms of percentage. In the case where the voltage and current are in phase, the power factor will be 100 percent or unity.

c. Power factor is an important consideration in connection with efficiently generating, distributing, and using large amounts of electrical power.

SECTION VI

INDUCTANCE

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64. General.—Inductance is the property of a circuit which opposes any change in the current flowing. The amount of opposition to the change of current depends on all the magnetic constants of the circuit. In other words, the reason that it is an opposition to the change of current is due to the voltages induced in the circuit itself by the changing magnetic field. Hence, anything concerning the circuit which affects the amount of flux would also affect this constant which is known as inductance. It was not considered in connection with direct currents for, as was said before, they do not change in magnitude. It is a very important consideration, however, when dealing with alternating current.

65. Unit and symbol for inductance.—*a.* The henry is the unit used to measure the inductance of a circuit. The henry can be defined as being the inductance present when a current change of 1 ampere per second in a circuit produces an induced e. m. f. of 1 volt. *L* is the symbol used for inductance.

b. Except for the larger iron cored coils, the henry is a larger unit of inductance than is convenient to use, therefore, in many cases the inductance will be given in millihenries or microhenries.

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66. Self-inductance.—*a.* When the effect of inductance is such as to cause the induced voltage to take place in the circuit where the changing current is flowing, the term "self-inductance" is often used. The unit and symbol of self-inductance are the same as those used for inductance in general. The amount of self-inductance a circuit has depends on its magnetic constants. Straight wires have negligible inductance effects at all but the extremely high frequencies. In ordinary low frequency power circuits, unless there are miles of transmission line, the inductance of straight wires can be neglected. On the other hand, when dealing with coils, especially with a magnetic material as a core, self-inductance can be very great, the amount being determined entirely by the number of turns, size, shape, type of winding, and other physical factors.

b. Self-inductance plays an important part in many electrical devices.

67. Mutual inductance.—When the effect of inductance is such as to cause an induced voltage in one circuit due to current changes in another circuit, the term "mutual inductance" is used. The same unit is used for measuring mutual inductance as for self-inductance. Where both self and mutual inductance is present in the same circuit, the letter *M* is used as a symbol for mutual inductance. The amount of mutual inductance, like self-inductance, depends solely on the physical factors which go to make up the circuit. Due to the fact that mutual inductance represents the effect of one circuit on another circuit, the two circuits concerned are said to be coupled together by mutual inductance, or sometimes the term "magnetic coupling" is used to indicate the presence of mutual inductance.

68. Coupling.—Many times it is desirable to transfer energy from one circuit to another circuit by making use of mutual inductance. The amount of energy that can be transferred depends on how much of the magnetic flux of the two circuits is common. In other words, if all the lines of force from the circuit carrying the original current cut or link all the turns of the other coil, there will be a maximum transfer of energy. Under the above conditions the two circuits are said to have maximum coupling. Since this condition can never absolutely be obtained, and many times the coupling is far from being this ideal maximum, an expression to give the degree or percentage of coupling is used. The maximum degree of coupling mentioned above is considered 100 percent coupling, or often just as unity coupling. If only half the lines of force cut all the turns or all the lines of force cut half the turns, the degree of percentage of coupling will be 0.5 or 50 percent. The only time that circuits even approach unity coupling

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is when the two coils concerned are wound on the same iron core. This will be explained in more detail when the theory of transformers is taken up.

69. Inductors in series.—*a.* Inductors are devices which are purposely added to introduce the property of inductance in the circuit. Inductors, like resistors, can be connected in series, parallel, or series-parallel. The total inductance of several inductors connected in series is equal to the sum of the individual inductors provided no coupling is present; in other words, $L_t=L_1+L_2+L_3+$etc. In case magnetic coupling is present, then the total inductance will either be more or less than the above value depending on whether the magnetic fields of the two circuits in question are in such a direction as

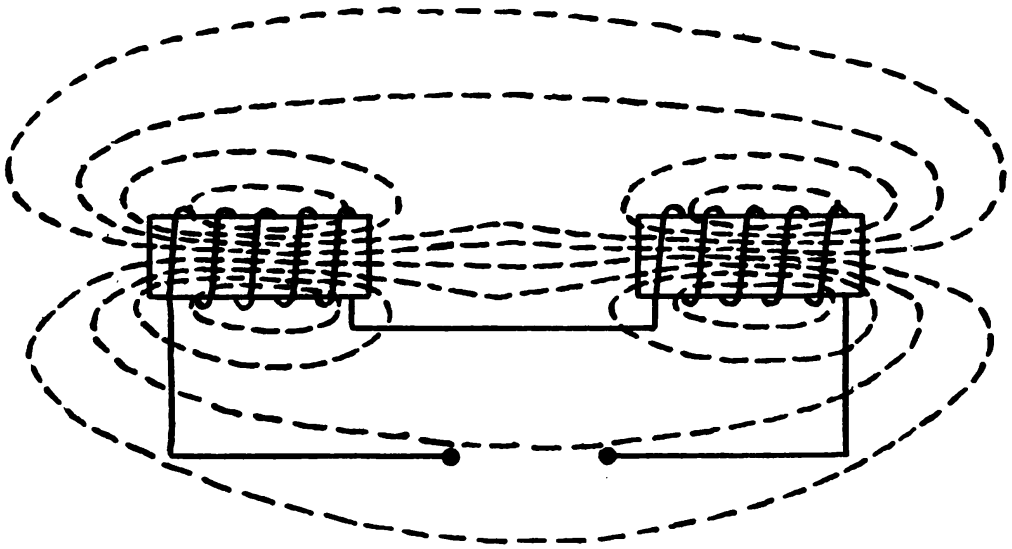


FIGURE 49.

to aid or oppose each other. Figure 49 represents two inductors connected in series with aiding magnetic fields.

b. Figure 50 represents two inductors connected in series with opposing magnetic fields.

c. The total inductance of inductors with coupling must take into account the amount of mutual inductance present. In other words, the formulas will be as shown below:

$$\text{Series aiding: } L_t=L_1+L_2+2M$$
$$\text{Series opposing: } L_t=L_1+L_2-2M$$

The above formulas could have been expressed as $L_t=L_1+L_2\pm 2M$.

70. Inductors in parallel.—When two or more inductors are connected in parallel, the total inductance will be less than any one of the individual inductors. Note that this is similar to resistors in parallel. If there is no coupling between inductors connecting in

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parallel, then the reciprocal of the sum of the reciprocal's formula as used in connection with resistors will apply; that is:

$$L_t = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \text{etc.}}$$

In case coupling is present, then due to the effects of mutual inductance the value will be different from that indicated by the above formula. The total inductance of inductors in parallel when mutual inductance is present is given by the formula:

$$L_t = \frac{1}{\frac{1}{L_1 \pm M} + \frac{1}{L_2 \pm M}}$$

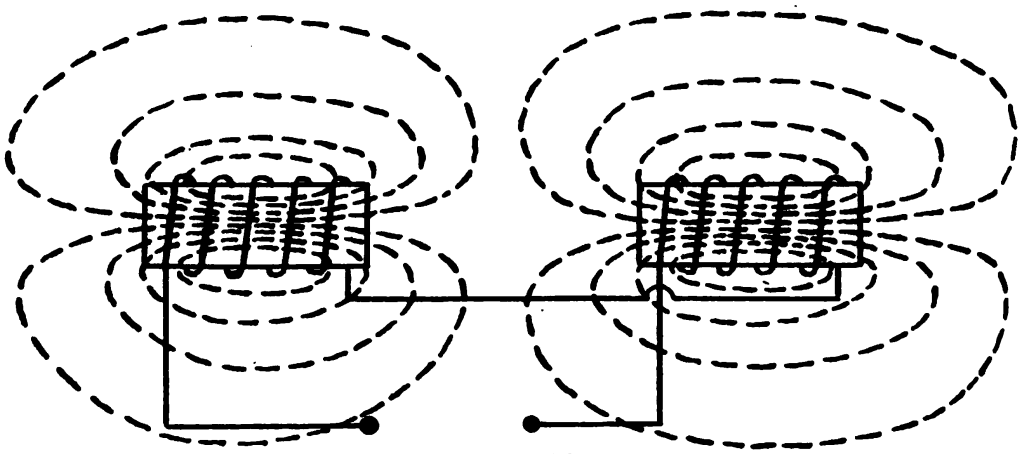


FIGURE 50.

71. Lenz's law.—A law which is very important when considering a. c. circuits containing inductance is known as Lenz's law. It can be stated as follows: An induced voltage either from the effects of self or mutual inductance is always in such a direction as to oppose the thing that is producing it. In other words, when a voltage is induced, the direction of this voltage will be such as to tend to make current flow in a direction to set up a magnetic field which will oppose the change in the original magnetic field. For this reason induced voltages are many times referred to as counter or back e. m. f.'s.

72. Inductive reactance.—*a.* As was stated before, inductance represents the property of a circuit which opposes a change of current and also causes counter voltages to be induced which act in the opposite direction to the applied voltage. Since it is the applied voltage that is causing the current to flow in an a. c. circuit, this counter voltage will be in a direction which will tend to oppose the flow of current in the a. c. circuit. This counter voltage is the reason that the imped-

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ance of an a. c. circuit with inductance present is greater than the resistance of the circuit. Since impedance represents an opposition to the flow of current and has the ohm as its unit, the effect which causes impedance to be greater than resistance should also be represented as an opposition to the flow of current and should have the ohm for its unit.

b. As was shown above, the real reason that impedance in inductive circuits is greater than the resistance is due to the counter voltage that is present. In order to get this effect in terms of opposition to current flow, a new term called *inductive reactance* is used and is represented by the symbol X_L. Since inductive reactance depends on the magnitude of the induced voltage, and this induced voltage in turn depends on the inductance of the circuit and also on the rate at which the current is changing, the formula for inductive reactance must necessarily have inductance and frequency embodied in it. The formula for inductive reactance is $X_L=2\pi fL$. Since π is a constant, approximately equal to 3.14, the formula could be written $6.28fL$. In other words, the constant 2π is necessary in order to make reactance come out in ohms when cycles per second are used for frequency and henries are used for inductance.

73. Phase relation of voltage and current in inductive circuits.—Since inductance is the property of a circuit which opposes a change of current, and in alternating circuits the current and voltage are continually changing, it is easy to see that one of the effects of inductance in an a. c. circuit is to cause the current changes to lag behind the voltage changes. In other words, the phase relation of voltage and current in an inductive circuit is that the current lags the voltage. In a pure inductive circuit, that is, a circuit with no resistance, the current will lag 90° behind the applied voltage. Of course, in all practical circuits there is some resistance for a coil must be wound with wire and even large copper wire has a certain amount of resistance. In practice, although the current may approach a 90° lag, it never actually lags that much.

74. A. c. circuits with inductance only.—As was stated above, it is not possible to have a circuit with inductance only, but for analyzing and solving certain problems it is desirable to consider this case as an example. If there is no resistance in the circuit, then the impedance will be equal to the inductive reactance, and Ohm's law under these conditions will be $I=\frac{E}{X_L}$; $E=IX_L$; $X_L=\frac{E}{I}$.

75. A. c. circuits with inductance and resistance in series.—*a.* In any a. c. circuit, Ohm's law can be stated as $I=\frac{E}{Z}$, but in order to

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solve circuits where inductance and resistance are connected in series, it is necessary to get an expression or a formula for Z in terms of R and X_L. Since R and X_L are both given in ohms it might first seem that the two would be merely added when they are in series. This is not the case, however, for in addition to opposing the flow of current, X_L causes the current to lag behind the voltage. For this reason, since the corresponding instantaneous values of voltage and current do not occur at the same time, the effects of resistance and inductive reactance in opposing the flow of current cannot be added arithmetically. As was also shown before, in a pure inductive circuit the current lags the voltage by 90°, and in a pure resistive circuit the current and voltage are in phase; that is, the current lags the voltage by 0°. Since the effects of inductive reactance and resistance have a 90° phase relation, the two can be combined by the use of a right triangle. (See fig. 51).

In other words, if the horizontal side represents R and the vertical side of the triangle represents X_L then the hypotenuse will represent Z.

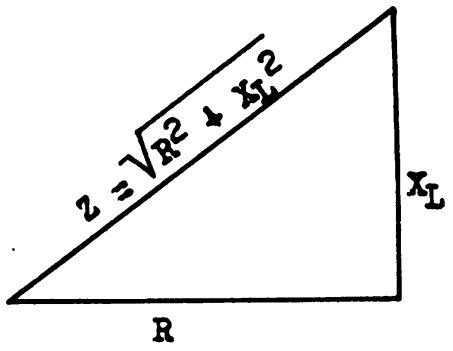


FIGURE 51.

To obtain the length of the hypotenuse of a right triangle in the terms of the two sides, it is merely necessary to use the well-known formula for a right triangle: The hypotenuse equals the square root of the sum of the squares of the sides. In other words, by using this triangle, a formula can be developed for Z where X_L and R are in series, that is $Z=\sqrt{R^2+X_L^2}$.

b. Consider the circuit shown below in figure 52 which represents an a. c. generator supplying power to an inductor and a resistor in series.

c. Of course in a practical circuit it might be merely supplying power to a coil, but for analyzing this circuit the d. c. resistance of the coil would be considered separately from the inductance of the coil and drawn as if a pure inductance in series with a resistor existed. The net effects would be the same in either case. In the above circuit the total voltage will divide and components will appear across the inductance and also across the resistance. From Kirchoff's voltage law

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it would appear that in this series circuit the total voltage would be equal to the sum of the voltage drop across the inductor and the voltage drop across the resistor. Again, due to phase relations, arithmetical addition cannot be used when applying Kirchoff's voltage law to a. c. circuits containing inductance. Instead the right triangle method must be applied. In other words, the total voltage can be considered as the hypotenuse, the voltage across the resistance as the horizontal side, and the voltage across the inductance as the vertical side. Since R and X_L cannot be added, it will not be possible to add I times R and I times X_L, which represent the two voltage values, by any means except those similar to the way in which R and X_L were combined to get the total equivalent effect or impedance.

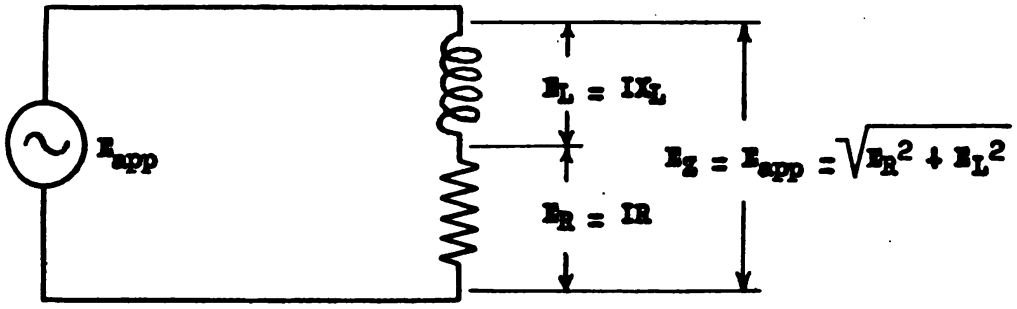


FIGURE 52.

SECTION VII

CAPACITANCE

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76. General.—Capacitance is the property of a circuit which opposes any change in voltage. Just as inductance is associated with the magnetic field of a circuit, capacitance is associated with the dielectric or electrostatic field of a circuit. Capacitance was not considered in connection with d. c. phenomena, for, as has been shown, the

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voltage is continuous and does not vary. It is just as important to consider the effects of capacitance in a. c. circuits as it is to consider the effects of inductance.

77. Unit and symbol for capacitance.—The farad is the unit used to measure the capacitance of a circuit. The farad can be defined as being the capacitance present when 1 coulomb of electrical energy is stored in the dielectric field of the circuit when 1 volt of e. m. f. is applied. This gives a simple definition of the unit of capacitance, but for practical purposes the unit is much too large. The microfarad or one-millionth of a farad is the practical unit for measuring capacitance. In connection with certain communication circuits, the micro-microfarad is used as a unit, that is, a millionth of a millionth of a farad. The symbol used for capacitance is C. From the above definition of the farad, it can be seen that $C=\frac{Q}{E}$ where C is the capacitance in farads, Q the quantity of charge in coulombs, and E the e. m. f. in volts.

78. Practical construction of condensers.—Any two conductors separated by a dielectric will have the property of capacitance. A condenser or capacitor is a device that is purposely constructed and inserted in the circuit to introduce the desired capacitance. From the above considerations it can be seen that to make a condenser all that is necessary is to have two or more metallic plates separated by air or some insulating material. The dielectrics in general use are air, mica, wax paper, oil, and, in certain types, an oxide gas film which is produced electrolytically.

79. Factors which determine capacitance of condenser.—*a.* The capacitance of a condenser is determined by several factors. Before considering these factors, it would probably be wise to find out just how the electrical energy is stored in the condenser.

b. In order to understand how the energy is stored in the condenser, figure 53, it is necessary to investigate the conditions in a charged condenser. Although the electrons from plate A are not actually transferred all the way around to plate B, electrons are taken out of plate A and electrons are added to plate B. This amounts to a separation of charges, and a dielectric field is established across the space between the two plates. It is in this dielectric field that all the energy is stored in a condenser having only a vacuum between plates.

c. Practically, a capacitor having a vacuum between the plates cannot be obtained, and even if it could be it would not be desirable. This will be apparent after the actions of insulating materials, or dielectrics as they are called, when used in this manner, between the plates of a condenser, have been investigated.

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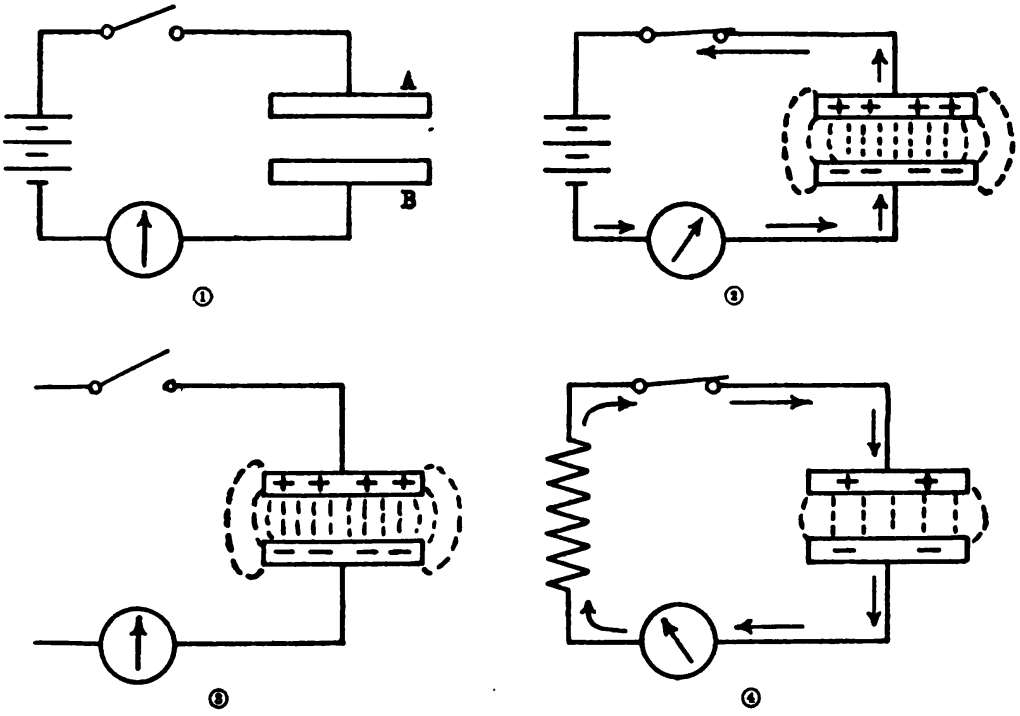
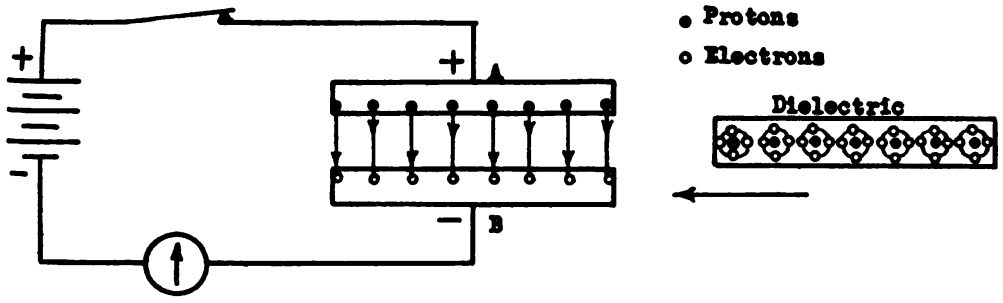
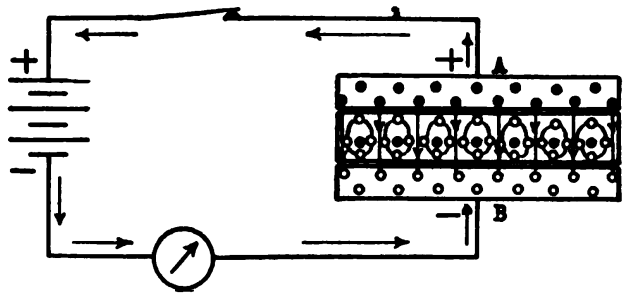


FIGURE 53.



① Charged condenser (vacuum).



② Additional charging current due to dielectric.

FIGURE 54.

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d. In figure 54① is shown a condenser connected to a battery and fully charged for the condition of vacuum between the plates. At the right is shown a piece of dielectric material about to be slipped between the plates of the condenser. When this is done, an additional charging current will flow as shown in figure 54②. This means that an additional amount of energy is now stored in the condenser. How can this be explained? The dielectric field between the plates cannot change, as the voltage across the plates does not change. The voltage is defined as the amount of work necessary to carry a unit charge from one plate to the other, working against the force which has been defined as the dielectric field. If this force is increased, the work necessary to carry a unit charge from one plate to the other would also increase. In other words, the voltage between the plates would have to increase to give a stronger dielectric field. However, the voltage remains the same because the plates are still connected to the opposite ends of the same battery.

e. The electron theory may now be made use of. In a piece of insulating material the arrangement of electrons and protons may be considered to be shown at the right in figure 54①. When this material is placed in a dielectric field, as between the plates of the condenser at the left, the electrons tend to move up the field. Since the electrons of an insulating material are not readily separated from the nucleus, the result is that the electrons rotate in distorted orbits as shown in figure 54②. This causes a dielectric field within the various atoms of the dielectric that is in opposition to the field caused by the charges on the plates of the condenser. Thus, the total dielectric field and hence the voltage cause more electrons to flow out of plate *A* and more into plate *B* until a net field equal to the original field is established. At this point the voltage across the condenser again equals that across the battery and the charging current ceases to flow. Thus, additional energy is stored in the distorted orbits of the electrons in the dielectric. Even a condenser using air as a dielectric can store slightly more energy than one having only vacuum between the plates due to the distortion of the electron orbits.

f. From the above considerations it can be seen that to store more energy a greater dielectric field or a greater distortion of the electron orbits in the dielectric will be needed. By making the area of the plates larger, the capacitance will be increased in direct proportion. Also by decreasing the distance between the plates the capacitance will be increased in direct proportion. In addition to the above, the capacitance depends on the dielectric constant of the material used in the condenser as a dielectric.

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g. The dielectric constants for some of the more common dielectric materials used in condensers are given below:

Dielectric material	*Dielectric constant*
Air	1.0
Mica	5.0 to 7.0
Waxed paper	2.0 to 3.2

h. The factors upon which the capacitance of a capacitor depends may now be summarized. Capacitance is directly proportional to the surface area of the plates in actual contact with the dielectric, is inversely proportional to the distance between the plates (or the thickness of the dielectric between them), and is directly proportional to the dielectric constant of the dielectric used.

80. Voltage break-down.—*a.* It has been shown that when a difference of potential is applied to opposite sides of an insulator a strain on the electron orbits in the material results. (See fig. 54.) The intensity of the strain depends upon the magnitude of the applied difference of potential. When condensers are connected in actual circuits, a potential difference or a voltage exists between one plate and the other. If the impressed voltage is great enough, it may cause a considerable force to act upon the electrons in the dielectric. In some cases this may produce a spark discharge through the dielectric, in which case electrons are caused to pass physically through the dielectric whether it be air, glass, paper, mica, or some other material. This actually punctures the insulating medium. In insulators like paper, mica, etc., a tiny hole is burned through by the spark. The voltage required to cause this effect is called the break-down voltage of the capacitor or the dielectric.

b. When the dielectric of a condenser of the mica or waxed paper type becomes punctured by the application of excessive voltage, a permanent short circuit occurs between the plates through the dielectric, and the condenser is worthless and is discarded. If the dielectric in an electrolytic or air type capacitor becomes punctured by excessive voltage, a short circuit also occurs between the plates, but as soon as either the voltage is removed or the capacitor is disconnected from the circuit the insulating value of the dielectric is automatically restored and the condenser is ready for normal use again. Dielectrics of this type are said to be self-healing.

c. The working voltage, that is, the maximum voltage which may be applied steadily to a condenser without harm, is usually marked on the case. Condensers connected in continuous or d. c. circuits are subjected to a voltage equal to the normal D. C. voltage of the circuit. In

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a. c. circuits, the voltage rises from zero to its peak value twice during each cycle, or 120 times a second for a 60-cycle source. As has been shown, the maximum or peak value of a sine wave alternating voltage is 1.41 times the effective value, and an a. c. voltmeter reads the effective value. Since the dielectric is subjected to, and must be able to stand without break-down, the peak value twice during each cycle, it is the peak value of the voltage which must be considered when selecting a condenser which is to work in an a. c. circuit or a pulsating d. c. circuit where the current is varying in value although continuous in direction. For instance, in an a. c. circuit in which a sine wave voltage having an effective value of 500 volts exists, the peak voltage applied to a condenser in the circuit is $500 \times 1.41 = 705$ volts. Therefore, a condenser having a d. c. working voltage of over 705 volts should be used rather than a 500-volt condenser.

d. As the manufacturers of condensers have no way of knowing whether their condensers will eventually be used in smooth d. c., pulsating d. c., or a. c. circuits, many of them mark both the d. c. and a. c. working voltages on them to eliminate the necessity for calculation on the part of the purchaser. Thus, a representative commercial condenser examined may have the following marking on its label: Cap. 2mf., Working voltage 400 volts D–C, 250 volts A–C. It must be remembered that the maximum or peak value is 1.41 times the effective value only in the case of a sine wave voltage. If the sine wave variation of voltage does not exist, this relation will be greater than 1.41 if the wave is greatly peaked and less than 1.41 if the wave is more flattened. In certain electrical circuits the voltage wave is more peaked than a true sine curve. Condensers for use in these circuits usually have a lower a. c. working voltage rating than would be obtained by dividing the d. c. working voltage by the factor 1.41. Thus, the condenser above rated at 400 volts d. c. would have an a. c. working voltage (as marked on the condenser of 250 volts) which allows it to be used on a voltage wave having an effective value of 250 volts and which is more peaked than a sine curve.

81. Condensers in series.—*a.* When two or more condensers are connected in series, the total capacitance is less than that of the smallest condenser in the circuit. In order to find the total capacitance of condensers connected in a series, it is necessary to use the reciprocal of the sum of the reciprocal's formula, that is:

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{etc.}}$$

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b. The reason for this can be explained by noting that the net effect of connecting condensers in series is really to increase the total dielectric thickness and thereby reduce the capacitance. (See fig. 55.) Thus, in figure 55 ①, electrons are transferred from one outside plate around through the external circuit to the other outside plate. The two center plates really do not add to the capacitance in any way, as the charges produced on them will be electrically opposite and will, therefore, neutralize each other. The effect then is the same as though the two inner plates were eliminated and the individual condensers C_1 and C_2 were replaced by a single condenser C having a total thickness of dielectric equal to the sum of the dielectric thicknesses of the individual condensers as shown in figure 55 ②.

c. The voltage break-down of condensers connected in series will be higher than that for the single condensers. Theoretically, it should

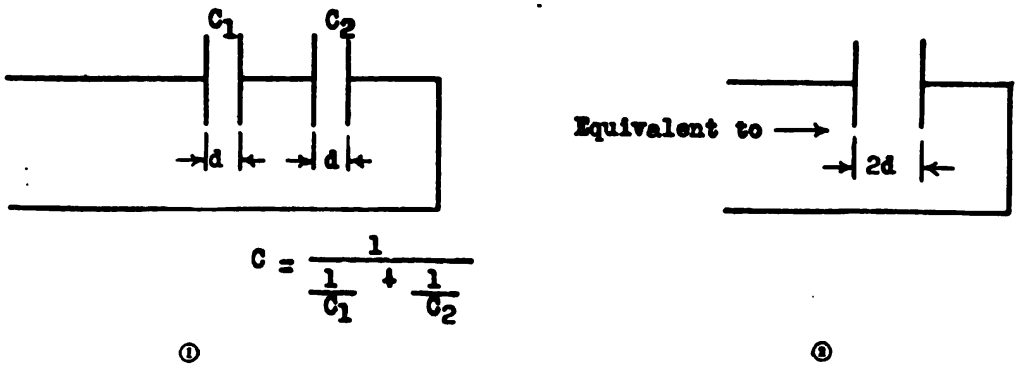


FIGURE 55.—Capacitors in series.

be equal to the sum of the voltage break-down ratings for each condenser. This may not be the case, however, when direct current is applied to the two condensers in series. The d. c. voltage will divide in a direct proportion to the d. c. resistance of the two dielectrics concerned, so that in case the insulating qualities of one condenser are better than those of the other, although the two capacitances may be equal, the d. c. voltage division may be unequal. This could be illustrated by the following example: Suppose two .1 mfd. 500-volt condensers were connected in series across a thousand volts. If the d. c. resistance of one was 45 megohms and of the other only 15 megohms, then the voltage across the 45-megohm condenser would be three times as much as the voltage across the 15-megohm condenser. Although each condenser has a working voltage rating of 500 volts, it would not be safe to put these two condensers in series across the thousand volt circuit, for as was shown above one of the

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condensers would have 666⅔ volts across it while the other would have only 333⅓ volts. This would mean that the one condenser would break down first, applying the whole thousand volts to the other condenser, which in turn would also break down.

82. Condensers in parallel.—When condensers are connected in parallel as in figure 56 ①, the effect is to increase the total surface area of the plates connected on each side of the line. Thus, in figure 56 ①, the area of plate A is added to the area of plate D, and the area of plate B is added to that of E, etc. The result is that the plate surface area is increased to the sum of the individual surface areas as shown in figure 56 ②, and the total combined capacitance is equal to the sum of the individual capacitances connected in parallel. This may be stated thus: $C_t = C_1 + C_2 + C_3 + \text{etc.}$ The voltage break-down of condensers connected in parallel must be taken as the lowest voltage break-down rating given to any of the individual condensers.

83. Direct current applied to condensers.—*a.* Although the effect of capacitance was not considered when developing the rules and

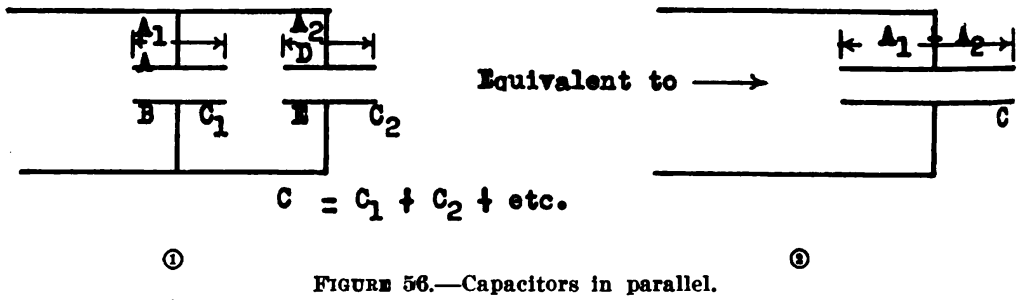


FIGURE 56.—Capacitors in parallel.

formulas to use in solving d. c. circuits, there is a momentary effect when a circuit is opened or closed such as might take place when a switch is operated, or when some vibrating or cam operated contact is made or broken as in a doorbell or ignition system of an automobile. As was stated above, capacitance is the property of a circuit which opposes a change of voltage. When a switch is closed even in d. c. circuits, the voltage must rise from zero to its final value. Also when the switch is opened or a vibrating contact breaks the circuit, the voltage must die down to zero. This means that under the conditions stated above the voltage is changing and there will be a momentary effect due to capacitance. It is easy to see why a condenser in series with a d. c. circuit will block the current since in effect there is an insulator inserted in series with the circuit, but at the moment the switch is closed the electrons will move into one plate of the condenser and move out of the other plate. The fact that these electrons are flowing in all parts of the circuit except across the actual dielectric of the con-

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denser means that there is a current flow in the circuit. This current flow will continue until enough electrons have been pushed into one plate of the condenser and a like number removed from the other such that the resulting e. m. f. built up on the plates of the condenser, due to the fact that they are now charged, is equal to the applied voltage. The length of time necessary to build up this e. m. f. is determined by the applied voltage, the resistance of the circuit, and the capacitance of the condenser. If the switch is now opened, removing the condenser completely from the circuit, this voltage will still be on the condenser plates. This can be verified by connecting a galvanometer across the condenser terminals and noticing the deflection. It is very important when condensers are connected across high voltage d. c. circuits to be sure and discharge the condenser, even if the line switch has been opened, before coming in contact with the terminals. Severe electrical shocks can be obtained by touching charged condensers.

b. Condensers are used in d. c. circuits to keep the voltage from pulsating. Certain d. c. generators have what is known as a commutator ripple. The reason for this will be explained later. What it means is that instead of a pure, steady, d. c. voltage, the voltage pulsates or varies slightly about the mean or average value. If a condenser of sufficient capacitance is connected across the terminals of this type generator, the capacitance will oppose this change of voltage and cause an almost pure d. c. voltage to be present. Another practical application of the condenser is in connection with vibrating contacts which have a tendency to spark if a condenser is not connected across them. When the contact is broken, the magnetic field collapsing induces a voltage which may be many times higher than the applied voltage. This induced voltage will cause a spark to jump across the contact provided a condenser is not there. In the event that a condenser has been connected across the contacts, instead of ionizing the air and causing a spark to jump across, the induced voltage will merely charge up the condenser. That is, the momentary current from the induced voltage flows into the condenser instead of jumping across the gap.

84. Alternating current applied to condensers.—As was shown above, the action of a condenser in a series d. c. circuit is to block all current flow except the momentary charging current when the switch is closed. On the other hand, in a. c. circuit, since the voltage and current are continually changing and periodically reversing, it can be seen that there will be a continual a. c. flow in all parts of the circuit except in the actual dielectric of the condenser. In other words, it can be considered that just about the time the cur-

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rent has ceased flowing into the plates of the condenser an alternation has been completed and the current is ready to reverse anyway, so the electrons that have just entered one plate come back out, go through the external circuit and into the other plate of the condenser. This process continues for each reversal of the alternating current. It should be realized that when a. c. flow through a condenser is spoken of, the current does not actually flow through the dielectric of the condenser, but instead the current flows in and out of the plates of the condenser. Since it flows in all parts of the metallic circuit, and even meters or lamp bulbs give an indicating when placed between two condensers in a series circuit, it is ordinary practice to say that alternating current will flow through a condenser.

85. Condenser losses.—*a.* Condensers, like any other device, are not perfect and there are certain associated losses which must be taken into consideration especially when the condenser is used in high frequency circuits. Condenser losses can be classified as either leakage losses or dielectric losses. Since there is no perfect insulator, a certain amount of actual current or electron drift will take place through the dielectric itself. As far as condenser action is concerned, this is a detriment and is classed under the losses. When alternating current is applied to condensers, the electron orbits of the atoms in the dielectric are continually being distorted in different directions. It takes energy in order to distort these electron orbits. The only place for this energy to come from is from the electrical circuit.

b. The losses occurring in condensers are not of much consequence except in high frequency circuits such as are used in communication.

86. Capacitive reactance.—As was the case with inductance, capacitance also gives an opposition to the flow of alternating current. It was shown above that the current flowing into the plates of the condenser built up a voltage on the plates which is opposite in direction to the applied voltage. Since this voltage is in the opposite direction to the applied voltage, it can be considered as a back or counter voltage. As was shown when considering inductive reactance, the effect of the induced counter voltage was to give an added opposition to the flow of alternating current. Likewise the counter voltage built up on the plates of the condenser gives the effect of an added opposition to the flow of alternating current. This opposition to the flow of alternating current which is due to the capacitance of a circuit is called capacitive reactance. The unit of capacitive reactance is the ohm and the symbol is X_C. The amount

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of capacitive reactance depends on the value of capacitance and the frequency. The formula for capacitive reactance is:

$$X_C = \frac{1}{2\pi fC}$$

It could also be written $X_C = \frac{1}{.628fC}$. In using this formula to get X_C in ohms, f must be in cycles per second and C in farads. Notice that in this case the opposition to the flow of alternating current is inversely proportional to the frequency and also to the capacitance, that is, the higher the frequency or the greater the capacitance the smaller will be the opposition or capacitive reactance.

87. Phase relations of voltage and current in capacitive circuits.—The effect of capacitance on the phase relation of voltage and current is opposite to that explained for inductance; that is, the current will lead the voltage in a capacitive circuit. It may be hard at first to visualize how current can actually lead the applied voltage, that is, build up and reach its peak before the voltage has built up and reached its peak. It is true that a voltage is required to cause the current to flow, so if the current flows ahead of the voltage and reaches its peak first, it must be doing this because of the counter voltage on the condenser. Probably a better way to analyze this effect of leading current would be to approach it from an entirely different viewpoint. When one thing is ahead, then the other must be behind. If the current leads when capacitance is in the circuit, then the voltage must lag. Since, from the definition of capacitance, it is the property of a circuit which opposes a change in voltage, then due to this opposition to the change of voltage, the changes which do take place in the voltage will lag behind the corresponding changes which take place in the current. Looking at it from this viewpoint it can be seen why the voltage lags the current, and as was stated before if the voltage is behind the current then the current certainly has to be leading the voltage. As in the case of inductance, the maximum phase angle for capacitive circuits is 90°. This can never be obtained in practice but can be approached much closer with condensers than with inductors.

88. A. c. circuits with capacitance only.—In the case of circuits which have capacitance only, the impedance will equal the capacitive reactance. An Ohm's law under these conditions will be:

$$I = \frac{E}{X_C}; E = IX_C; X_C = \frac{E}{I}$$

89. A. c. circuits with capacitance and resistance in series.—*a.* As in the case of inductance and resistance in series, an expression

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or formula for Z in terms of R and X_C is needed. Also, since the effect of X_C in a pure capacitive circuit is such as to cause the current to lead the voltage by 90°, a method similar to that applied to the inductive circuit can be used here. The right triangle for determining a value for Z in terms of R and X_C can again be used. If one side is represented by R and the other side by X_C, then the hypotenuse will correspond to Z. This leads to the formula of $Z = \sqrt{R^2+X_C^2}$. Consider the circuit shown by figure 57 which represents an a. c. generator supplying power to a resistor and condenser in series.

b. In the above circuit, as with any other circuit having components in series, the total voltage divides and appears as a voltage

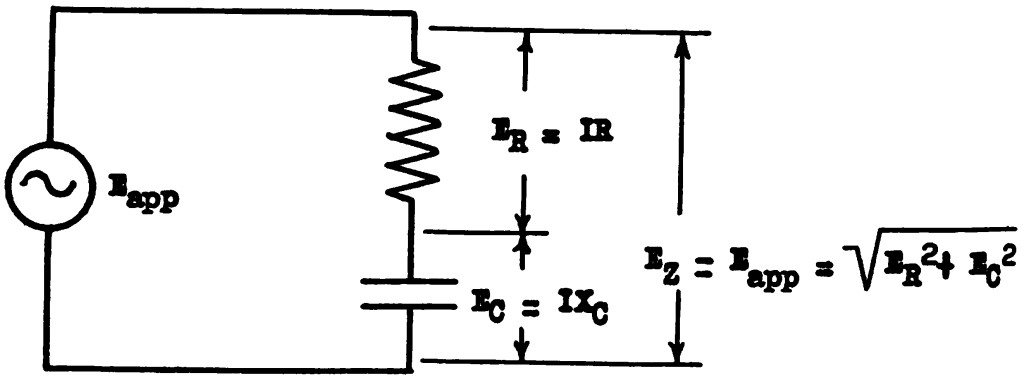


FIGURE 57.

drop across the individual components. In this case there will be a voltage drop across the resistor and also across the condenser. But, as in the case of inductance and resistance in series, these voltage drops do not add up arithmetically to give the total applied voltage. The reason for this is the same as that given in the case of inductance and resistance. To make Kirchoff's voltage law hold true in this case, the right triangle method of adding the components must be used. In other words, the hypotenuse will represent the total voltage, one side will represent the voltage across the resistance, and the other side will represent the voltage across the condenser. The total applied voltage will be numerically equal to $I \times Z$, the voltage across the resistance will be the same as for direct current or $I \times R$, and the voltage across the condenser will be $I \times X_C$.

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SECTION VIII

POWER EQUIPMENT

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90. General.—*a.* This is the age of electrical appliances. Much of the drudgery in household duties has been abolished by the extensive use of electrical energy to accomplish the work. Electrical power is used in almost every step in the process of manufacturing. The smallest shoe repair shop has quite an outfit of electrical power equipment; and about the first thing a building contractor does, even in connection with the construction of a small residence, is to bring in a temporary power line, for portable drills, saws, etc., have replaced the old time hand tools. Alternating current has almost replaced direct current for light and power, although direct current is still used in most cities for the elevators and street cars.

b. A comprehensive treatise on the generation, control, transformation, distribution, and use of electrical energy for light and power would require volumes. It is the purpose of this section to explain briefly certain power equipment and its use.

91. Transformers.—*a.* The study of transformers is merely the continuation of the study of mutual inductance and coupling. The transformer is a device for raising or lowering alternating voltage. If the voltage is higher after transformation, the transformer is referred to as a step-up transformer. A step-down transformer gives a lower voltage in its output than that applied to its input.

b. Transformers are constructed by winding two separate coils on an iron core so they will be closely coupled by mutual inductance. (See fig. 58.) The coils are insulated from each other and also from the core.

They are usually wound one on top of the other and assembled on the core as shown by figure 59. The coil to which the voltage is applied is called the primary winding, and the coil from which the transformed voltage is delivered is called the secondary winding.

c. With core arrangements as shown in figures 58 and 59, the coupling between primary and secondary approaches unity, for prac-

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tically all of the lines of force from the primary link with all the turns of the secondary.

d. The voltage ratio of a transformer is the ratio of the primary and secondary voltages. The voltage ratio is the same as the primary and secondary turns ratio. If we represent the primary and sec-

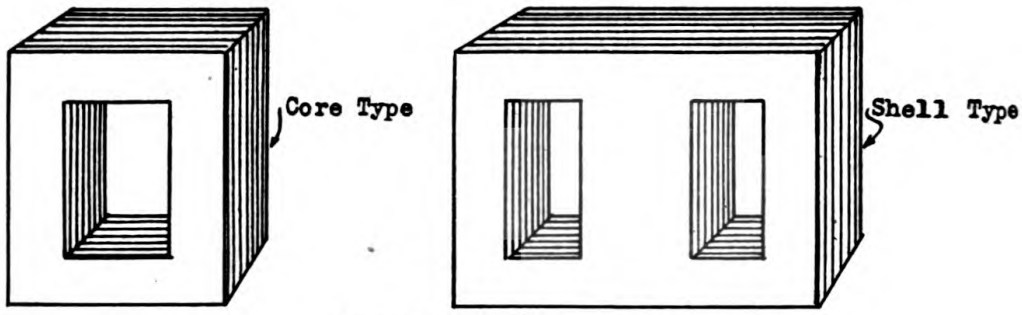


FIGURE 58.—Transformer cores.

ondary voltages by E_p and E_s and the primary and secondary turns by T_p and T_s then the equation can be written

$$\frac{E_p}{E_s}=\frac{T_p}{T_s}$$

e. From the above equation it can be seen that a step-up transformer has more turns in the secondary winding than in the primary winding. Also if the voltage is stepped up ten times, then the

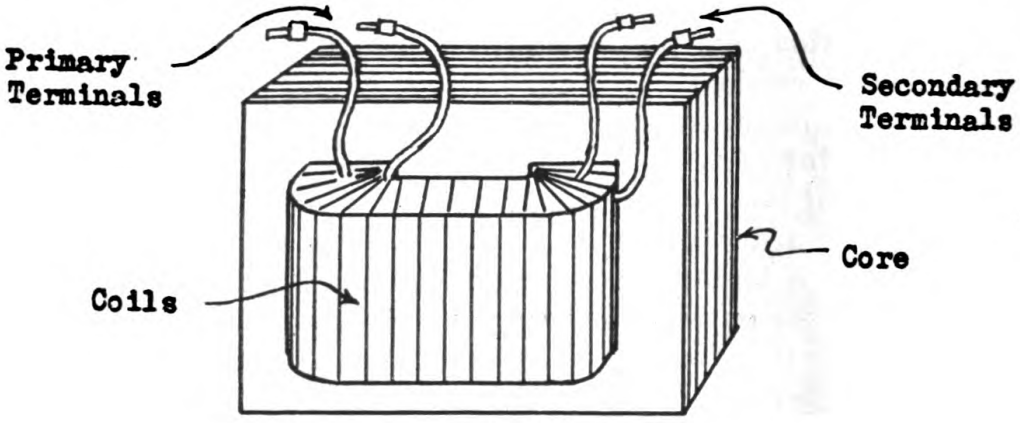


FIGURE 59.

secondary coil has just ten times as many turns as the primary coil. On the other hand, a step-down transformer has more turns in the primary winding than in the secondary winding.

f. The same transformer can be used as either a step-up or a step-down transformer provided the proper voltage is used. For instance, a transformer designed to step 110 volts down to 5 volts for ringing a doorbell has a voltage ratio and therefore a turns ratio of 110/5=22. Ordinarily it would be used as shown in figure 60.

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g. Any a. c. voltage of the same frequency up to 5 volts could be applied to the original secondary winding and be stepped-up to a value 22 times as great. In this case the original secondary of the step-down transformer would automatically become the primary of a step-up transformer. The transformer windings are designed and insulated for a certain voltage, so in the above case the mistake of trying to use the 22 to 1 step-down 110-volt transformer to step 110 volts up to 2,420 volts should not be made. In the first place, the 110 volts would probably burn out the 5-volt secondary winding, and even if it did not the 2,420 volts would damage the original 110-volt winding. In other words, a transformer can be used either as a step-up or step-down transformer, but care must be taken not to exceed the original voltage ratings of either primary or secondary coils.

h. Neglecting losses, the power in the secondary is equal to the power in the primary. Remembering this it can be seen that if the voltage is stepped-up the current must have been stepped-down, for power is equal to volts times amperes, so if one goes up and the power

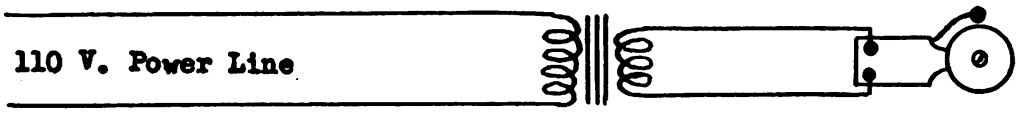


FIGURE 60.

stays the same the other must go down. This leads to the relation of the currents and turns ratio which can be written

$$\frac{I_p}{I_s}=\frac{T_s}{T_p}$$

i. When the load in the secondary circuit is changed, the secondary and also the primary current change. The change of primary current due to changing a resistance in an entirely separate electrical circuit may seem perplexing at first. Of course it could not be any other way, for with the primary and secondary voltages fixed, if the load resistance connected to the secondary is made smaller the secondary current will go up. This means the secondary power is greater, and since the primary circuit furnishes the power to the secondary, the primary power also must be greater than before the load was changed. Since the primary voltage is constant, the increase in power must be due to an increase in primary current. The above relation of currents and turns ratio can be transposed to read thus: $I_p=I_s\times\frac{T_s}{T_p}$

j. This shows that the primary current is equal to the secondary current multiplied by a constant. (The ratio of the turns cannot change.) This means that any time the secondary current increases

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or decreases for any reason the primary current will do likewise. For this reason a short circuit in the secondary is just as bad as a short circuit in the primary. Another way to explain why the primary current is affected by the secondary load resistance is from a reactance viewpoint. With an open-circuited secondary there is a very small primary current flowing due to the high inductive reactance of the primary winding. When a load resistance is connected across the secondary and secondary current starts to flow, the magnetic field produced by the secondary current is according to Lenz's law in a direction to oppose the field of the primary which produced it.

k. Now the inductive reactance of the primary is due to the primary field, so the effect of the secondary current in opposing this primary field is to reduce the inductive reactance of the primary circuit and hence allow more current to flow in that circuit. In the case of a short circuit on the secondary, the large secondary current is enough to reduce the inductive reactance of the primary circuit practically to zero and hence give the same result as an actual short circuit in the primary circuit itself.

l. The efficiency of a device is never equal to 100 percent, but because there are no mechanical moving parts in a transformer the efficiency is very high. A well-designed transformer made of good materials may be 98 or 99 percent efficient. Transformer losses are divided into those occurring in the windings and in the iron core. These losses are usually referred to as copper and iron losses, respectively.

m. The copper loss is an I^2R loss due to the primary and secondary currents flowing through the wires which have some resistance.

n. The iron losses are of two kinds. First, the changing magnetic field induces currents in the iron which is a conductor. These currents, called eddy currents, extract power from the source since they are in effect small shorted secondaries. These eddy current losses would reach serious proportions if special care were not taken to break-up these eddy current paths. This is accomplished by making the core of transformers from thin sheets, insulated from each other, instead of using a solid piece of iron. These thin sheets are called laminations.

o. The second kind of iron loss is known as hysteresis loss. This results because a certain amount of energy is required to reverse the magnetism in the iron core. In other words, the atoms or molecules of the core must be swung back and forth at the frequency of the alternating current which is being transformed. This energy must come from the electrical source and represents a loss. Certain iron

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and steel are much easier to magnetize and demagnetize than others. An alloy of silicon and steel is used extensively for transformer laminations.

92. D. c. generators.—*a.* The fundamental a. c. generator which was described in section V can be converted to a d. c. generator by substituting an automatic switching device known as the commutator in place of the collector rings used on the a. c. generator. Figure 61 shows the fundamental d. c. generator with a simple two segment commutator. This simple commutator for a single coil consists of a split ring having two segments insulated from each other and also from the shaft. The commutator rotates with the shaft, and the stationary contact brushes both rest against it. The position of the brushes is such that at the instant the current reverses in the armature coil the brushes are disconnected from the segments to which

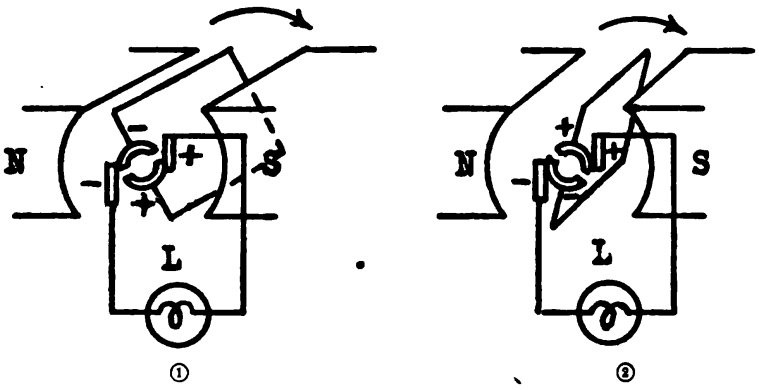


FIGURE 61.—Action of commutator in d. c. generator.

they were originally touching and start making contact with the opposite segments. Thus, when the current reverses in the coil, the contacts to the external circuit reverse also and, although alternating current still flows in the coil, the current in the external circuit is always in the same direction. (See fig. 61.)

b. The voltage and current produced by the fundamental d. c. generator, although it flows in only one direction, is not ordinary direct current. This current and voltage is continually changing in magnitude from zero when the coil is vertical to a maximum when the coil is horizontal. In other words, the current flows in pulses, hence the term "pulsating d. c." Pulsating d. c. is not desirable for most purposes. For this reason the practical d. c. generator has many coils and commutator segments so arranged as to produce an almost steady direct current and voltage. Thus, while one coil is at the zero position another is at the maximum position. In other words,

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when a large number of coils are evenly distributed one is generating a maximum voltage almost all of the time.

c. Of course the resultant steady voltage will be more than the maximum generated by one of the coils. The resultant voltage is obtained by adding the instantaneous voltages from all the coils. The instantaneous and resultant voltages for a single, four, and eight coil generator are shown in figure 62.

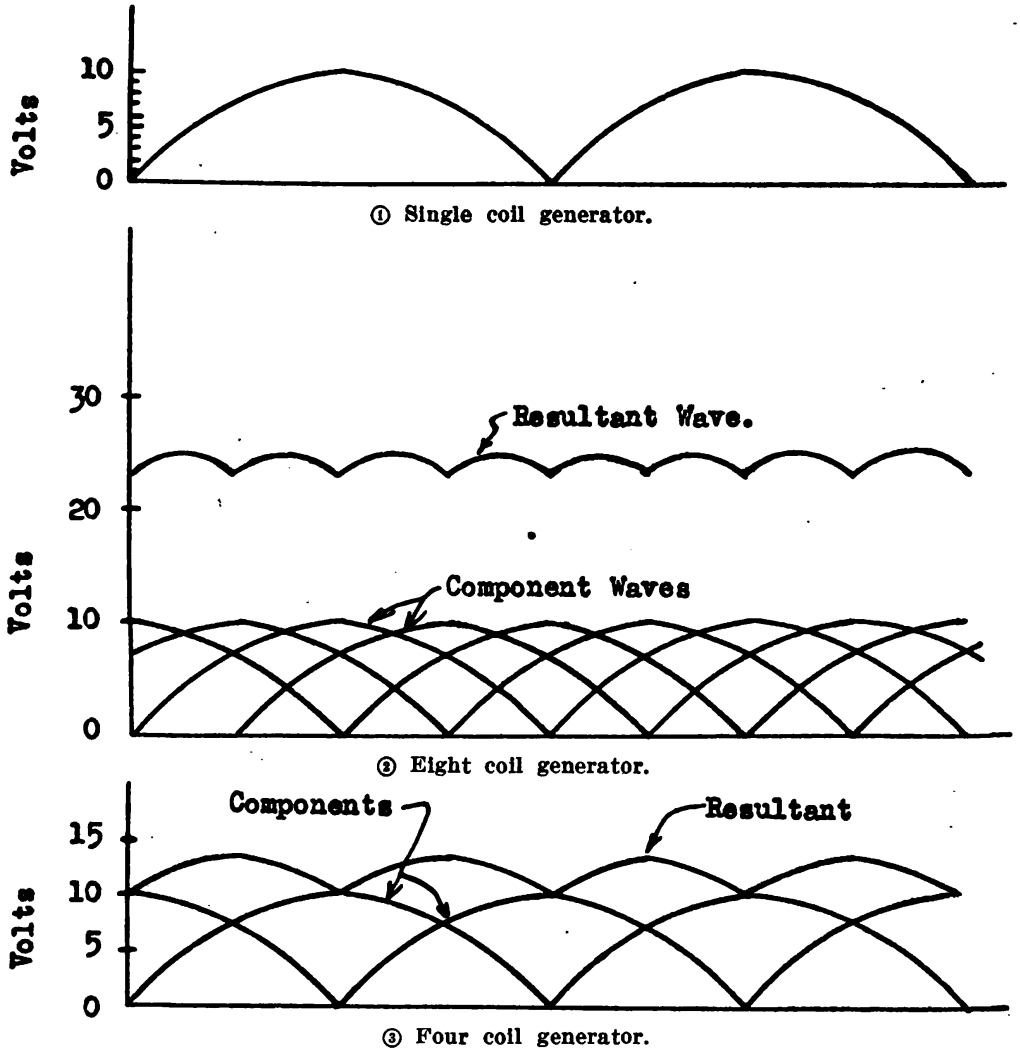


FIGURE 62.

d. As the number of coils increases, the generated voltage gets larger as well as becoming more steady. The frequency of pulses also increases as the number of coils is increased. The small pulses in d. c. generators are referred to as commutator ripple. These have no serious effect for most power purposes but can give considerable disturbance in radio work. As was stated before, a large condenser

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connected across the brushes will smooth out these ripples. Sometimes in addition to the condenser which opposes the change of voltage, an inductor called a choke is connected in series with the line to oppose the small changes (ripple) in current. The condenser or condenser choke arrangement is called a ripple filter. Figure 63 illustrates various parts of the d. c. generator.

e. D.c. generators are classified according to the method of connecting the field coils and the armature. The generator's field coils are the electromagnets which produce the flux that is cut by the rotating coils. The rotating assembly including the iron core, shaft,

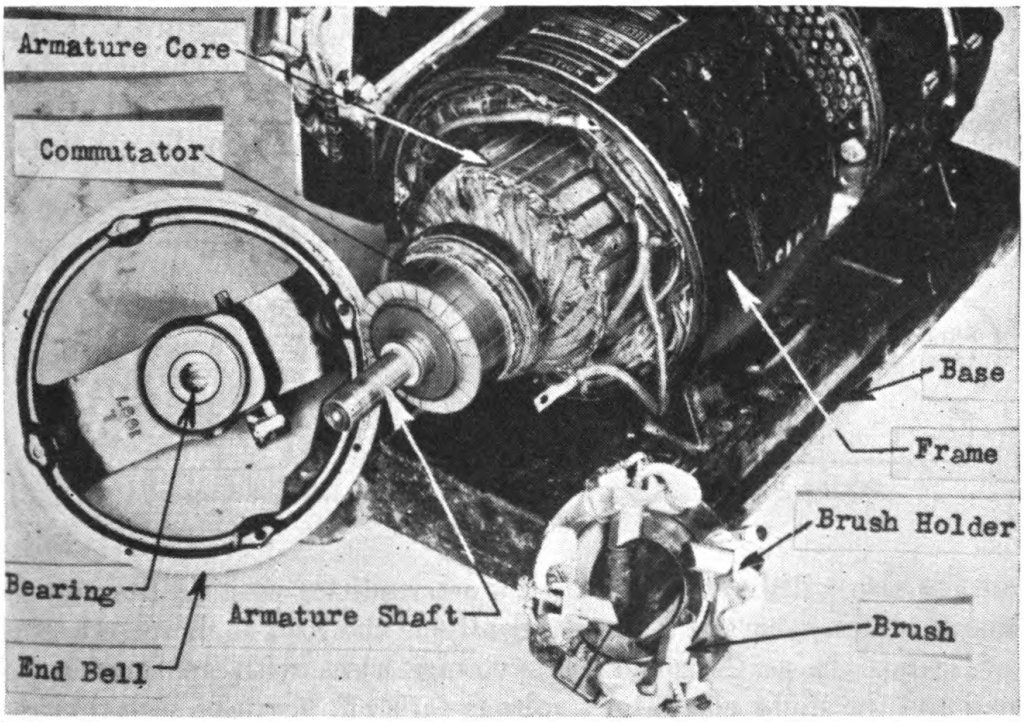


FIGURE 63.

and commutator is termed the armature. When the field coils and the armature are connected in series with each other the machine is called a series generator. If the armature and field are connected in parallel a shunt generator is the result. Certain generators have the field winding in two parts, one of these field windings being connected in series and the other connected in parallel. This type of generator is called a compound generator. Figure 64 shows the series, shunt, and compound generator schematically.

f. Since the series field winding must carry all of the generated current it must be wound of heavy wire and usually has only a relatively small number of turns. The shunt winding, being connected

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directly across the generated voltage, is wound with a large number of turns of wire and hence has only a small portion of the total armature current flowing through it.

g. Each type of machine has its advantages and disadvantages. Shunt and compound machines are used to the greater extent. The terminal voltage of any generator is dependent to some extent on the amount of current the generator is furnishing to the load. The voltage of a series generator increases as the load is increased. The additional load current increases the magnetic flux and thereby increases the generated voltage. The terminal voltage of the shunt generator falls off as the load is increased due to the voltage drop in the armature. This is due to the resistance of the armature winding. The result of the terminal voltage being less than the generated voltage means that the shunt field current will be less due to the smaller terminal voltage applied to it. For this reason the generated

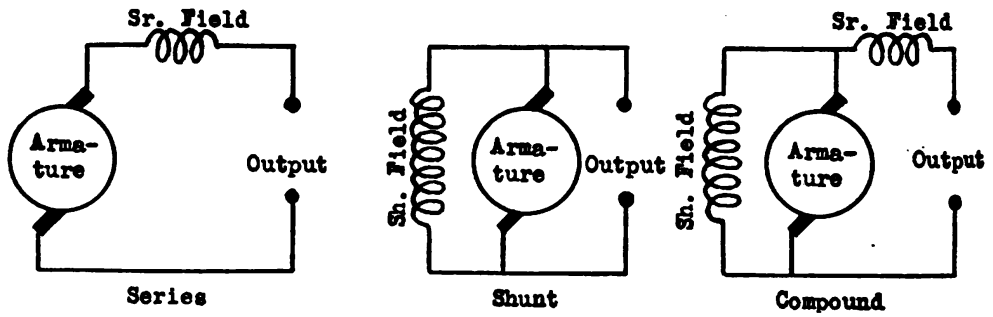


FIGURE 64.

voltage also will become less with a net result of making the voltage from a shunt generator fall off rapidly as the load is increased.

h. Since the series generator's voltage rises with an increase of load and the shunt generator's voltage falls off, it can be seen that the tendency in a compound generator is for a constant output voltage as the load is changed. This cannot be accomplished absolutely but can be approached.

i. The voltage output of a generator may be changed by either changing the speed of rotation or by changing the amount of magnetic flux produced by the field coils. The latter method is usually used by inserting a field rheostat in series with the shunt field winding. (See fig. 65.) (A rheostat is a variable resistor.)

j. Increasing the resistance of the field rheostat will decrease the generated voltage since it will decrease the field coil current and hence the magnetic flux produced. Decreasing the resistance of the field rheostat will increase the voltage generated.

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93. D. c. motors.—*a.* D. c. motors and d. c. generators are very similar. In fact, any of the above described generators will run as a motor and convert electrical energy into mechanical energy if the proper voltage is applied to the terminals. The proper voltage is the same as that which is generated when the machine is rotated at the proper speed. Motors are also classified as series, shunt, and compound machines, and are represented schematically the same as the corresponding generators.

b. The main characteristics of motors are the starting torque and the variation of speed with a change in mechanical load. The series motor has a very high starting torque, but its speed falls off rapidly as the load is increased. On the other hand, if the mechanical load is removed entirely the motor will speed up to an enormous value. For this reason series motors must be coupled to the load by some

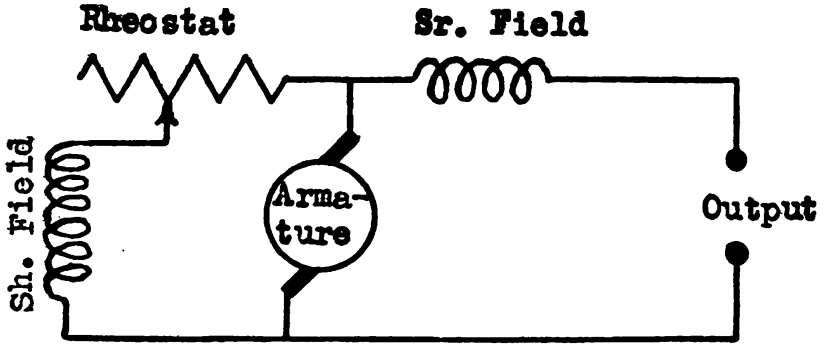


FIGURE 65.

secure method such as direct, gear, or chain drive. Belts should never be used. At present, series motors find their greatest use in streetcars and elevators. Also automobile starting motors are series motors.

c. Shunt motors have a relatively low starting torque but within limits have a constant speed with load variations.

d. The compound motor can be designed to have to a certain extent the desirable characteristics of both the series and the shunt motors, that is, a fair starting torque and also a fair speed characteristic.

94. Armature testing.—*a.* Although there are many types of armature windings, practically all the present-day machines use closed circuit windings of either the lap or wave type. Low and medium voltage machines use the lap winding while the wave winding is only found on high-voltage machines. Figure 66 shows the connections to the commutator of a lap-wound armature having two brushes and eight commutator segments.

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b. Wave windings are laid out differently and connected to different commutator segments but are similar to the lap winding to the extent that the end of one coil and the beginning of the next are connected to the same commutator segment. For this reason the method of testing armatures described below can be used for either lap or wave windings.

c. To test an armature for grounds is very simple. It is only necessary to use an ohmmeter or other continuity tester and check between the commutator and the shaft or core. (See fig. 67.) Figure 67 also shows how to test the armature for open or shorted coils. For this test the brushes should be lifted if the armature has not been removed from the frame. To interpret the open and short test refer to figure 66 and notice that when the ohmmeter is between any two adjacent segments there will be (if there exists no open or short) one coil in

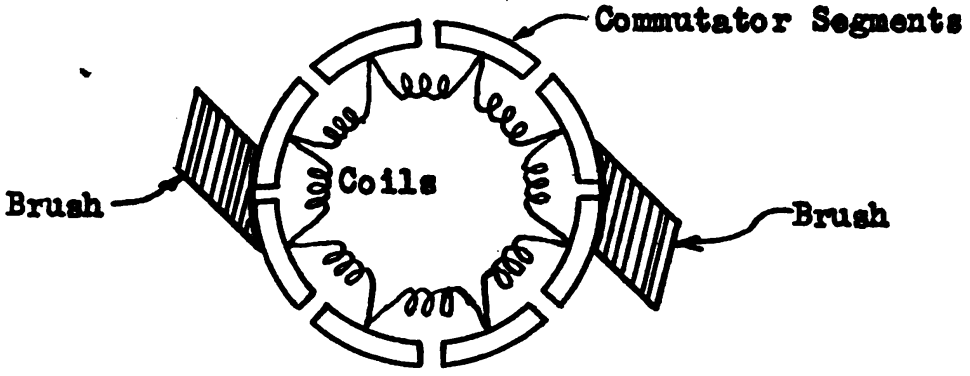


FIGURE 66.—Lap wound armature.

parallel with the rest which are in series. In this case if each coil has a resistance of 0.5 ohm the equivalent circuit will be as shown in figure 68.

d. This total resistance can be found by applying the formula:

$$R_T = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\text{etc.}} \text{ or}$$

$$R_T = \frac{1}{\frac{1}{.5}+\frac{1}{7\times.5}} = \frac{1}{\frac{1}{.5}+\frac{1}{3.5}} = \frac{1}{\frac{16}{7}} = \frac{7}{16} \text{ ohm.}$$

Regardless of which two adjacent segments are being tested the ohmmeter should read the same. If any two adjacent segments give zero resistance then that coil is shorted. On the other hand, if the ohmmeter reading between any two adjacent segments is higher then that coil is open. For this armature an open coil should give a reading of $7\times.5=3.5$ ohms, as then there would be 7 coils in series without the

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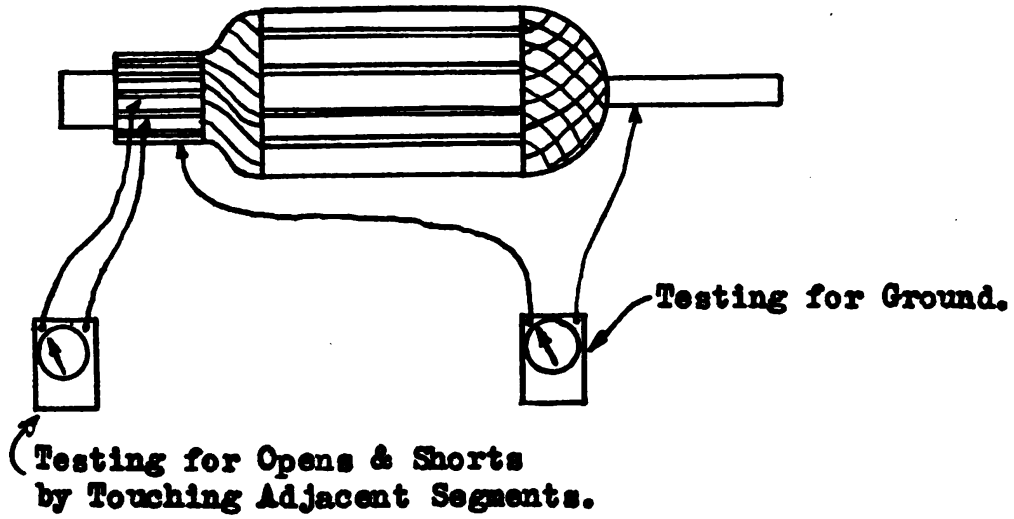


FIGURE 67.

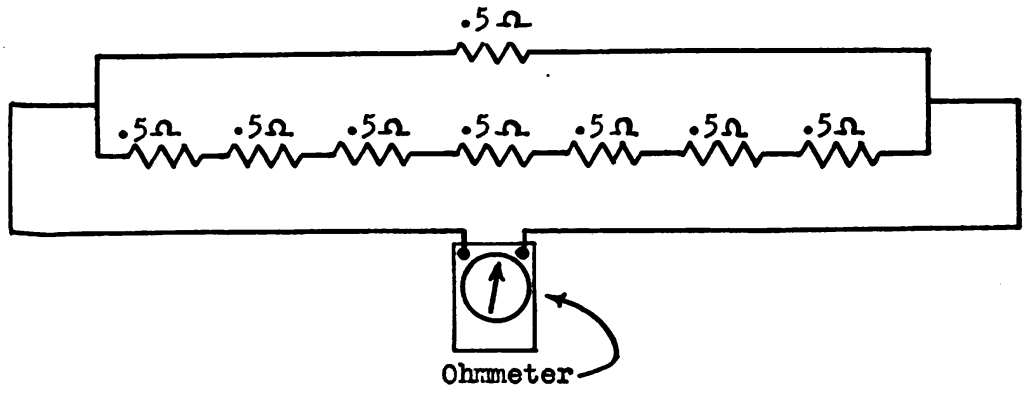


FIGURE 68.

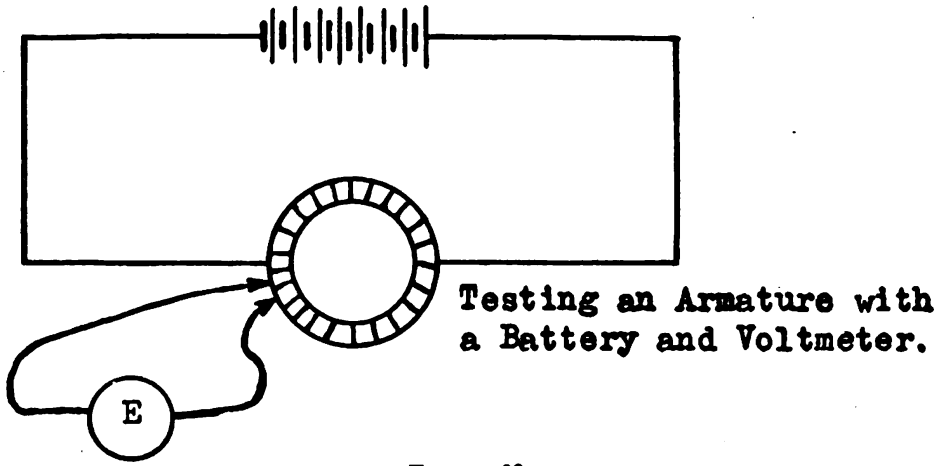


FIGURE 69.

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one coil in parallel with them. It is not necessary to know the resistance and make the above calculation. A comparison is all that is necessary.

e. The same results may be obtained by the use of an applied voltage and a low range voltmeter as shown in figure 69. In this case the same voltage should be obtained between any two adjacent segments. Zero voltage represents a short circuit while a higher voltage represents an open circuit.

f. A device for quickly localizing the trouble in armatures which is used in repair and rewinding shops, is called the growler. The growler receives its name from the relatively loud 60-cycle hum and chatter which are due to the fact that the armature under test is held in a V-shaped slot of the core of an a. c. electromagnet by its

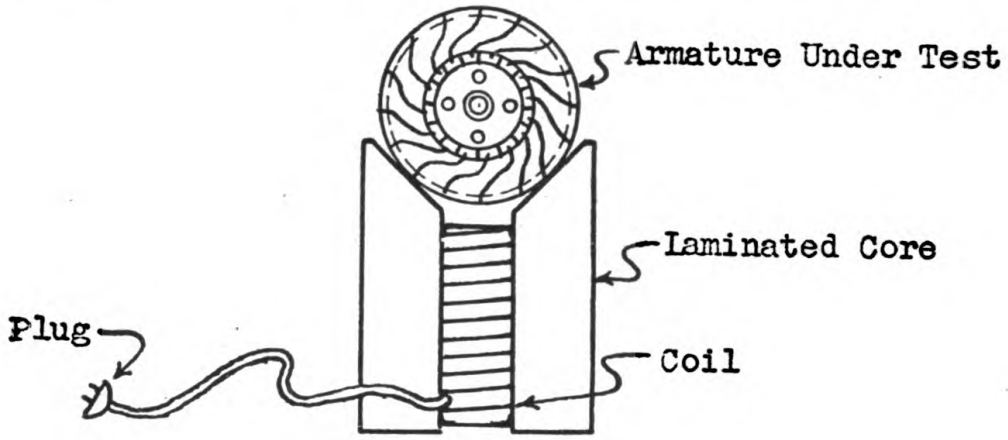


FIGURE 70.

weight only. Figure 70 shows an end view sketch of an armature resting on the growler core.

g. The armature completes the magnetic circuit and its windings act as the secondary of a transformer with the growler coil forming the primary. Charred insulation is indicated immediately by its becoming red hot and starting to smoke. Short and open circuits are tested for by turning the armature and exploring the armature core with a thin strip of iron or steel, such as a hacksaw blade. Since the armature winding is symmetrical the hacksaw blade will be attracted the same regardless of the position of a good armature. On the other hand, a shorted armature coil will cause a place of stronger attraction while an open will cause a place of weaker attraction for the hacksaw blade.

95. A. c. generators.—*a.* As was stated at the beginning of this section, alternating current has almost replaced direct current for

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light and power uses. The a. c. generator, which is usually called an alternator, has the same principle of operation as the fundamental a. c. generator explained in a previous section. About the only place where a. c. generators will be encountered is in centrally located power plants. Many times these power plants are located at points greatly remote from the places where the power is to be used. In other words, they may be located where cheap water power is available. This means then that in order to transmit and distribute this power efficiently the voltage must be extremely high. A. c. generators have been designed to generate voltage actually as high as 13,200 volts. For long distance transmission even this voltage is not high enough to get economical results. Many times the voltage is stepped-up by transformers to hundreds of thousands of volts and again stepped-down near the place where it is to be used. Most lighting is accomplished by single phase alternating currents, while the power required for factories and industrial use is usually three phase. Three phase merely means that the generator's windings are distributed such that there will be three individual a. c. voltages generated which are 120° out of phase with each other. Since they are 120° out of phase with each other, they can be transmitted over three wires without interfering and can be separated into three individual single phase alternating currents at the other end of the transmitting system if desired.

b. Referring to the explanation of the fundamental a. c. generator it was seen that a single coil was rotated between the pole pieces of an electromagnet. This electromagnet must be supplied with direct current to produce a magnetic field which is always in the same direction. In practical alternators the d. c. current for magnetizing the field coils is referred to as the exciting current. Many times this current is obtained from a small d. c. generator which is connected to the same shaft as the alternator. This unit is called the excitor. As has been shown before, voltages will be induced any time there is a relative motion of the magnetic field such as to cut across a conductor. This means that in the alternator the field coils can either be stationary and the conductors in which the voltage is induced be revolved, or the inductors in question can remain stationary and the field coils be revolved. Since the field coils are excited at relatively low voltages, say 250 volts d. c., and on the other hand the voltage induced or generated by the alternator may be as high as 13,200 volts, it is preferable to have the high voltage induced in stationary windings and merely take the low 250 volts into the machine through sliding contacts. When a generator is made in this manner, it is

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said to be of the revolving field type, and the stationary winding, where the voltage is generated, is termed the stator winding.

c. In the fundamental a. c. generator a cycle was generated for each revolution of the coil. This was because there were only two poles so that, as a coil successively went by one north and one south pole, two alternations or one cycle would be generated. In the practical alternators, however, instead of only two poles they frequently have many poles. In this case a cycle will still be generated each time a north and a south or, in other words, a pair of poles has been traversed by the inductor. In this case the frequency will not be one cycle per revolution but must be obtained from the following formula:

$$f = \frac{\text{number of poles}}{2} \times \frac{\text{speed in r. p. m.}}{60}$$

The first part of the formula represents the number of pairs of poles, and the second part is needed to give frequency in cycles per second since the speed of rotating machinery is usually given in revolutions per minute (r. p. m.).

96. A. c. motors.—*a.* The two main types of a. c. motors are the synchronous motor and the induction motor. Each has its advantages and special uses. The synchronous motor is constructed exactly the same as an alternator. In other words, any alternator will run as a synchronous motor providing the proper voltage is applied. The speed of the synchronous motor will be exactly the same as the speed of an alternator of similar construction, i. e., the same number of poles. Thus, it is seen that the speed of a synchronous motor is determined by the frequency of the alternating current from which it is running. The small motors in electric clocks are of this type, and providing the power company can maintain its frequency constant, the clock will neither lose nor gain time.

b. Most of the smaller a. c. motors are of the induction type. The principle of the induction motor is the same as that of the transformer with the exception that the secondary winding is wound in such a way and mounted on bearings such that the magnetic fields due to the secondary current react on the magnetic fields due to the primary current in a manner that will produce rotation. It can thus be seen that there is no electrical connection between the revolving part of an induction motor and the stationary part. Like an alternator the stationary part is referred to as the stator and the revolving part is called in this case the rotor. Induction motors can be made very rugged and will give long trouble-free service. Three-phase induction motors are used in industry almost exclusively for furnishing power for the various

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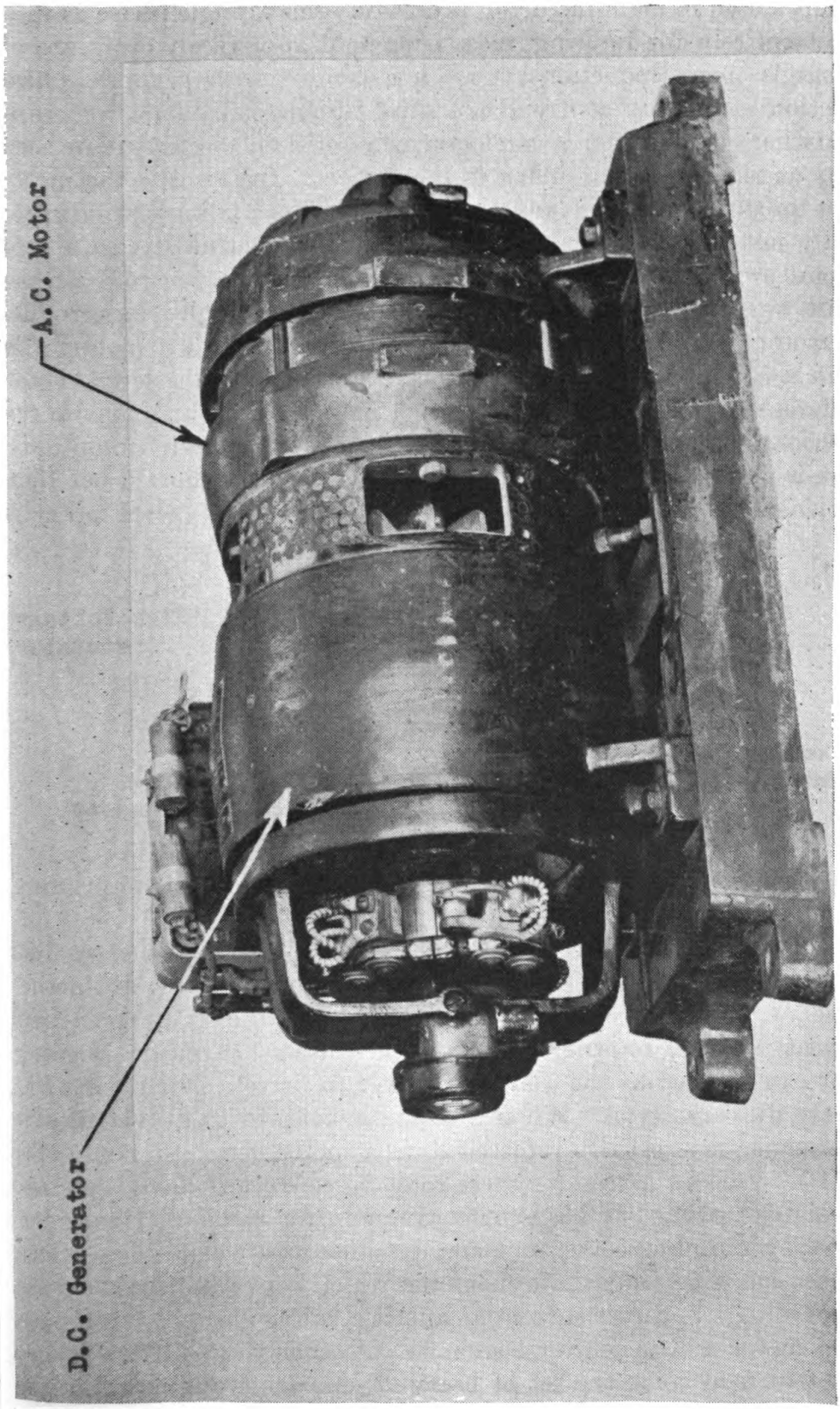


FIGURE 71.—Motor generator.

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machines used in manufacturing processes. Since single phase is used almost entirely for lighting, most household appliance motors are of the single phase induction type. The trouble with a single phase induction motor is that it will not start automatically unless there is an auxiliary winding or a condenser connected in the circuit in such a way as to cause a lead or lag in the current. In this case the motor starts up as a two phase induction motor. This auxiliary winding is usually not large enough to carry the current continually, so a centrifugal switch is incorporated which cuts this winding out of the circuit when full speed has been reached. These single phase induction motors have similar characteristics to the shunt d. c. motor. To get an a. c. motor with starting torque comparable to the series motor a different principle must be used for starting. For this purpose the induction repulsion motor is used. This type motor has a commutator which is used while the motor is being started, but is shorted out by a centrifugal switch after the motor has started. This type of motor is

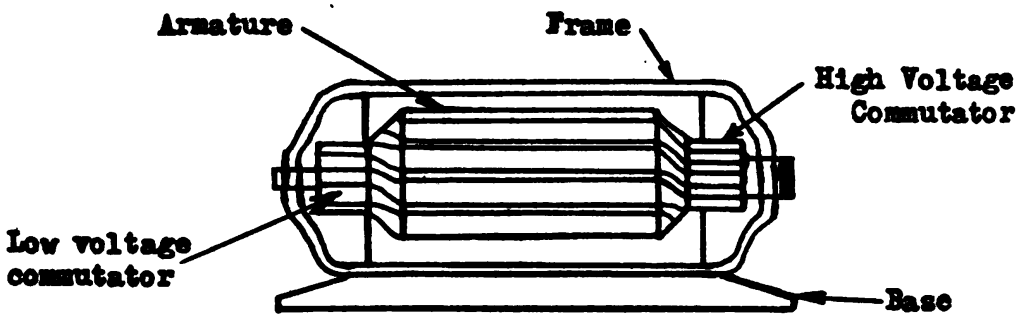


FIGURE 72.—Cutaway view of dynamotor.

used when it must start up under load such as in air compressors, refrigerating units, etc.

97. Rotating converters.—For converting electrical energy from a. c. to d. c., d. c. to a. c., or a. c. of one frequency to a. c. at another frequency, or perhaps from d. c. at one voltage to d. c. at an entirely different voltage, rotating converters are used. In other words, a motor can be used as the source of power to drive a generator of an entirely different type. When a motor is coupled to a generator in this manner it is usually referred to as a motor generator set. (See fig. 71.) Various names for these rotating converters have been used to designate particular kinds of conversion, for instance, rotary converters, synchronous converters, and dynamotors are examples. Some of these machines like the dynamotor which converts direct current at one voltage to direct current at another voltage have certain parts of the motor and generator common. In other words, there is only one set of field coils, one set of bearings, one armature core, but two separate armature windings and commutators. (See fig. 72.) Dyna-

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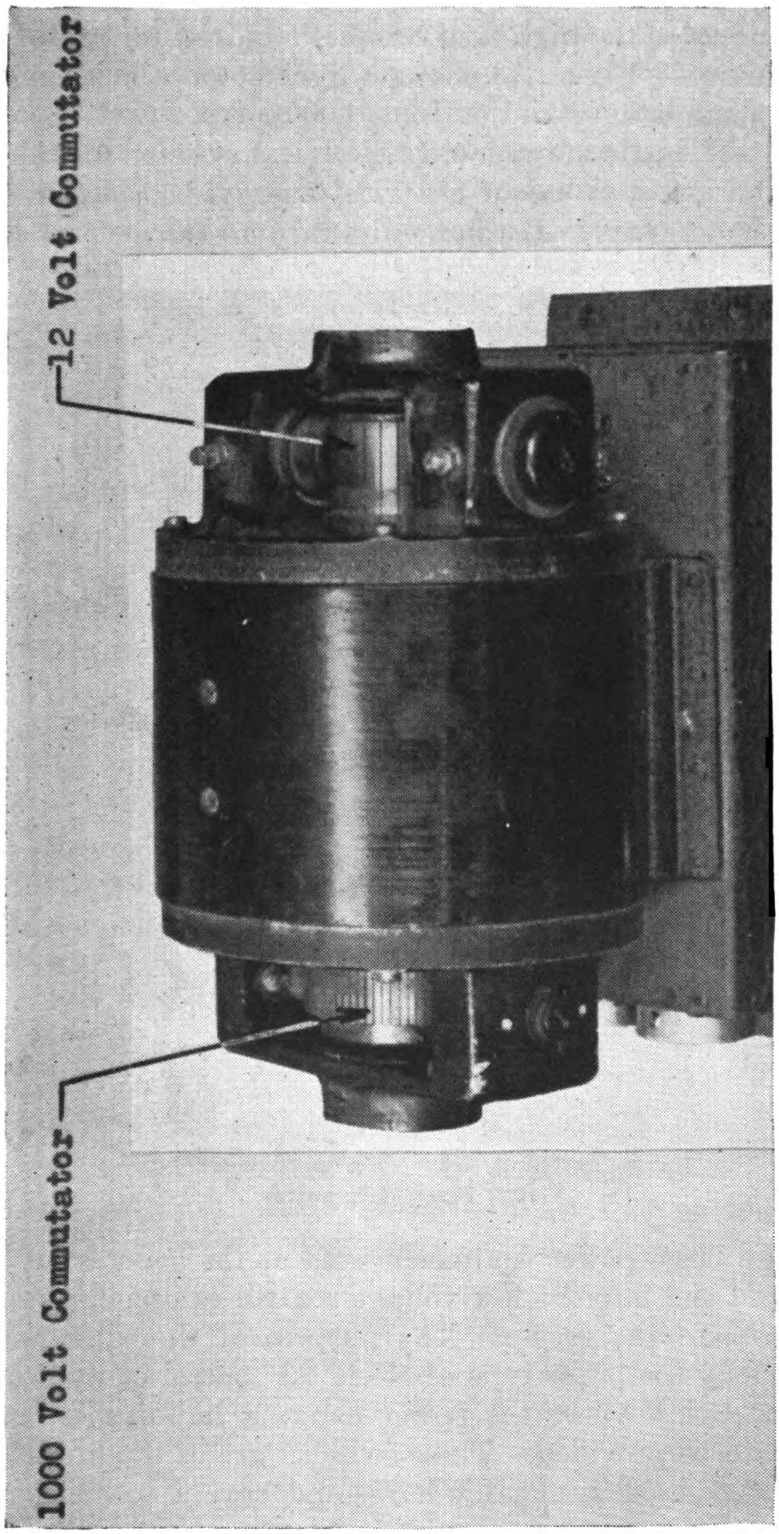


FIGURE 73.—Dynamotor.

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motors are used considerably in connection with portable communication systems to convert the voltage of a 6- or 12-volt automobile or airplane battery to the high d. c. voltages required for radio receivers and transmitters. Figure 73 shows a dynamotor which runs from a 12-volt airplane battery and delivers 1,000 volts.

98. Control equipment.—*a.* In electrical systems for the generation, distribution, and use of electrical energy, considerable control equipment is necessary. It can be divided into the general classes of

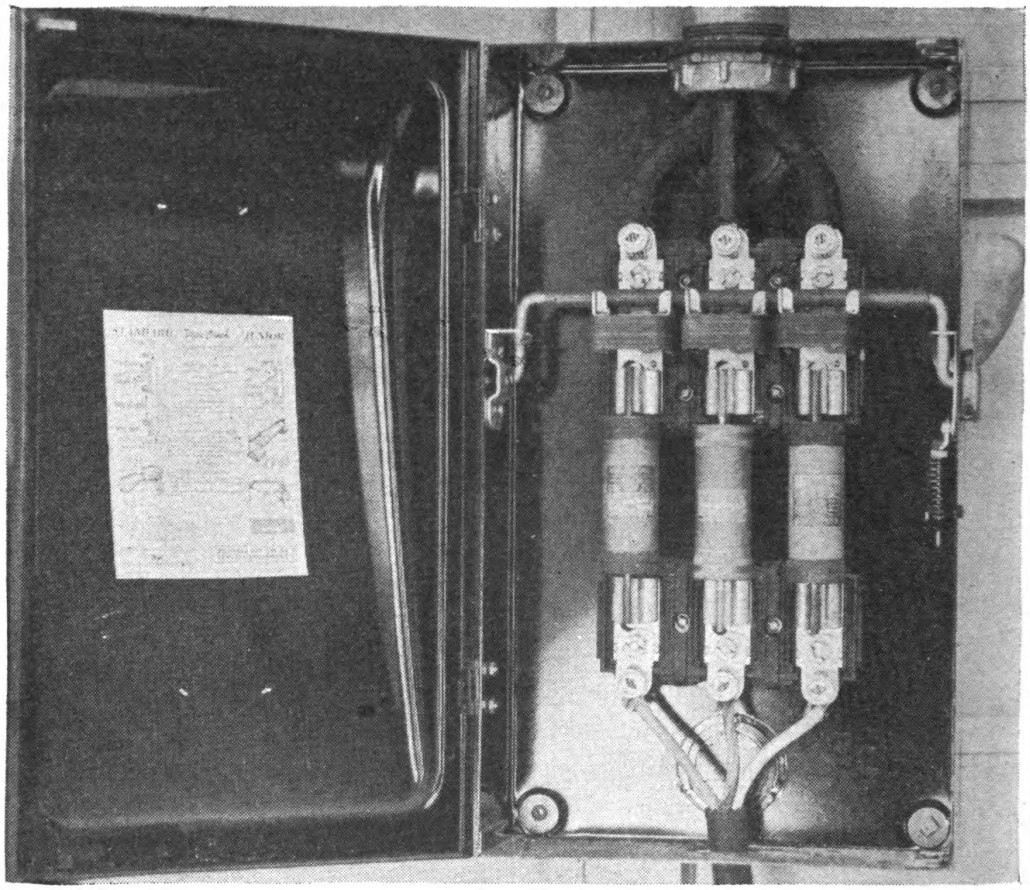


FIGURE 74.—Safety switch.

high voltage large power equipment used at the generating and distributing end and into the low voltage control equipment used at the receiving end of the system. The purpose of this discussion is to consider briefly the latter type of electrical control equipment.

b. At the point where the power enters a building, a main line switch should be provided. These switches are of the knife type but are usually enclosed in metallic boxes and have a special spring arrangement which gives a very quick break when the switch is opened. Switches of this kind are classified under the general term of safety switches. (See fig. 74.)

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c. Even with the quick break mentioned above, it is not desirable to open the circuit under full load conditions by this type of switch. At the various points where considerable power is used, the circuit is usually made and broken by magnetic contactors. These are switches which are remotely controlled by push buttons which cause current to flow through an electromagnet which in turn pulls the switch contacts together. Any electric arc that may be formed is between the two replaceable contacts which are protected by a composition cover.

d. In starting all but the very small electric motors, it is not desirable to apply the full voltage while the armature or rotor is stationary. The reason for this is that the resistance of the armature is very small, and hence an excessive current will flow until a speed has been reached which will provide a sufficient counter e. m. f. to hold the current down to a normal value. To keep this current from being excessive while the motor is obtaining full speed, resistance must be inserted in series with the d. c. armature and gradually removed as the motor obtains speed. Often this is accomplished automatically by a device called a motor starter. There are automatic starters on the market for starting motors regardless of the size of the motor. (See fig. 75.)

e. In the generation and distribution of electrical energy it is important to keep the line voltage constant as the load or speed changes. Where the load changes gradually or at certain predetermined times, the voltage may be regulated by increasing or decreasing the excitation by a manually controlled field rheostat. In other installations where the load may fluctuate rapidly, it is desirable to provide an automatic voltage regulator. Several types of automatic regulation have been developed. The vibrating contact type of voltage regulator is the one usually found on small generators, such as automobile or airplane battery charging units, and hence will be the only one described here. In this type regulator a resistance is inserted in series with the field winding but is shorted out by a pair of contacts held closed normally by a spring. As long as this resistance is shorted by the contacts, the generator will produce maximum voltage at a certain speed. Included in the regulator is a magnetic coil which is excited by the generator's output voltage. In case the voltage becomes excessive, this coil will be energized to such an extent as to force the contacts open and hence insert the above-mentioned resistance in the field circuit. This resistance is large enough to cause the voltage generated, if it continually stays in the field circuit, to be less than that desired. The effect is as follows: When the voltage drops below the desired value, the strength

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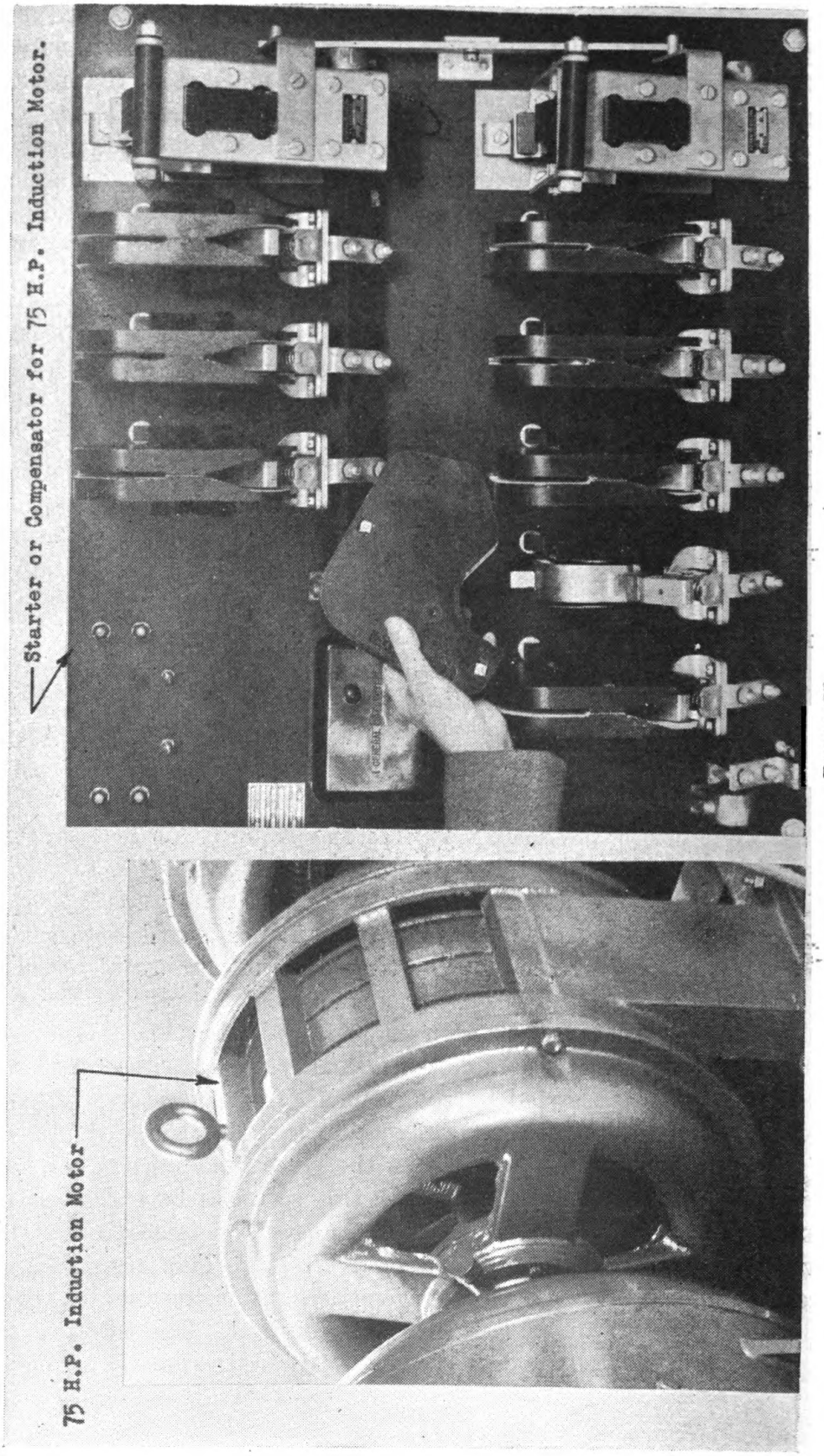


FIGURE 75.

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of the regulator's coil will be insufficient to hold the contacts open and the spring will again close them. This causes the voltage to rise above the desired value. In fact, the regulator contacts vibrate at sufficient frequency to keep the voltage pulsating very slightly above and below the desired value. For all practical purposes it can be considered to be constant at exactly the value required. Of course, as was mentioned before in connection with commutator ripple, if

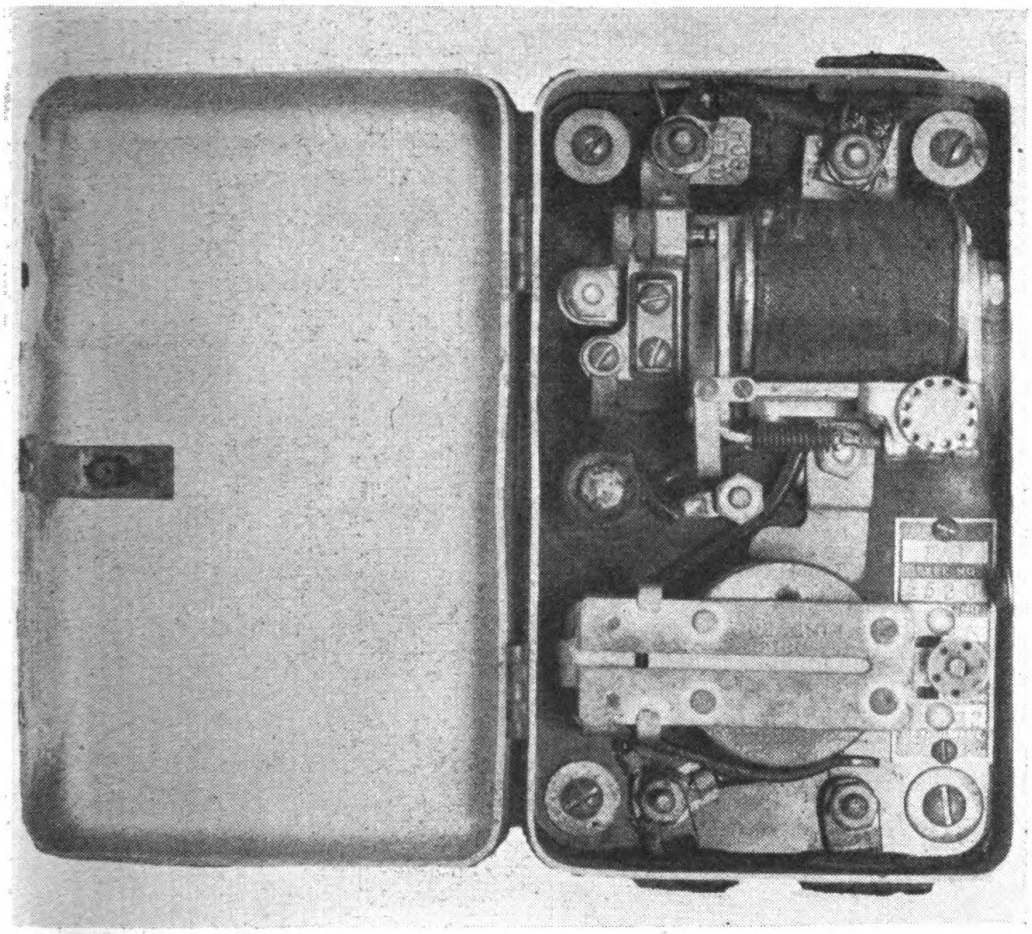


FIGURE 76.—Voltage regulator.

absolutely continuous direct current is required, a ripple filter must be incorporated.

f. A condenser is also connected across the vibrating contact points to keep them from sparking and becoming pitted. A modern regulator of this type is slightly more complicated than the fundamental principle just outlined. (See fig. 76.)

g. To protect electrical equipment and the wiring which furnishes the current from damage due to short circuits and overloads, fuses or circuit breakers are usually incorporated.

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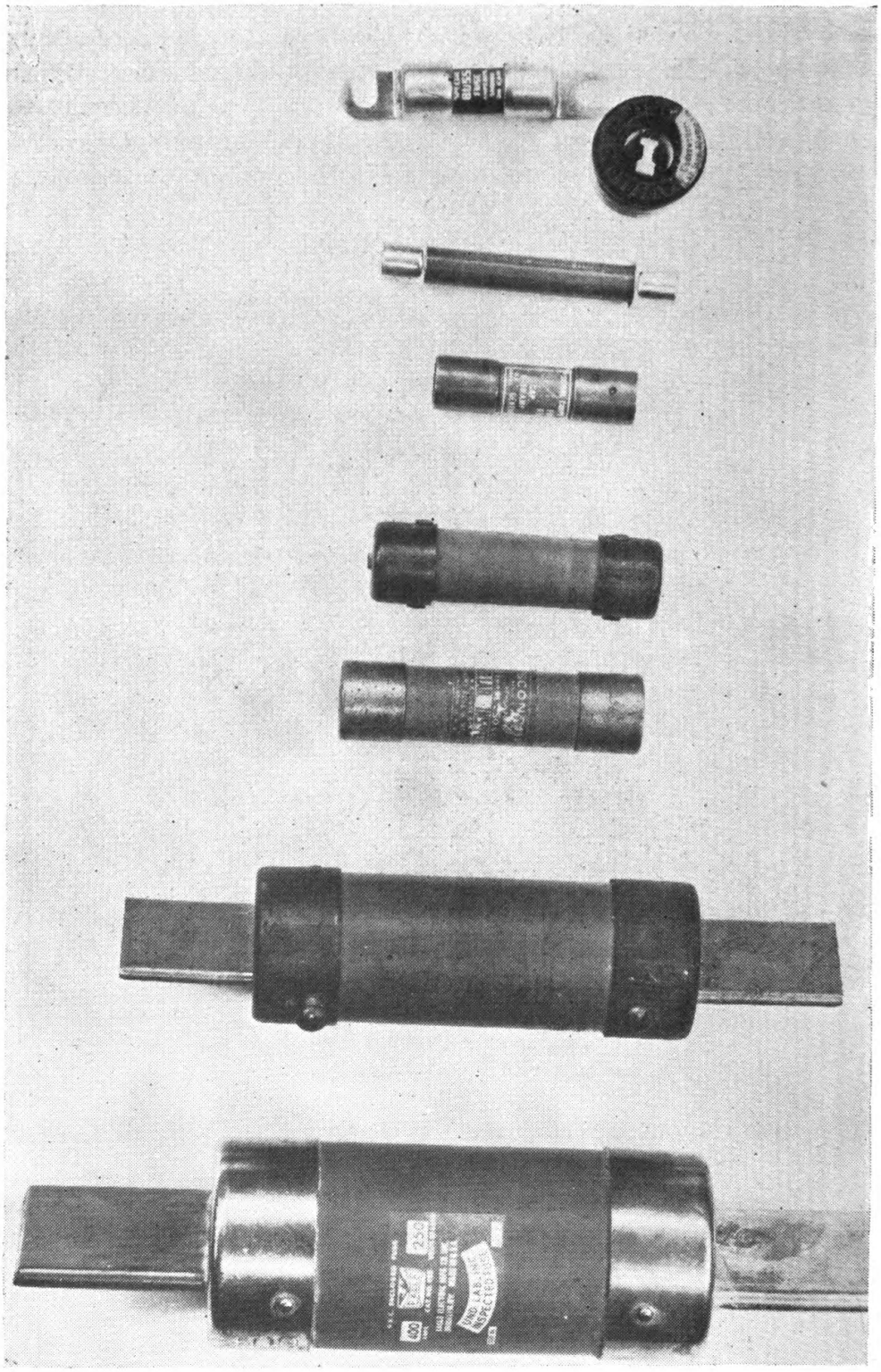


FIGURE 77.—Various types of fuses.

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h. The fuse is a device for inserting in the circuit a strip of metal which melts at a relatively low temperature. The heat produced by the current flowing through this fuse is proportional to the power, and since power is equal to I^2R the fuse will melt if the current gets above a certain limit. (See fig. 77.)

i. To keep from replacing so many burned out fuses, many installations are incorporating circuit breakers. A circuit breaker is similar to the magnetic contactor explained above except that most of them must be closed manually and are held closed by a latch mechanism. A magnetic tripping coil is connected in series with the circuit. If an excess current flows through this tripping coil the circuit breaker will open. In this case all that is necessary to restore power is to

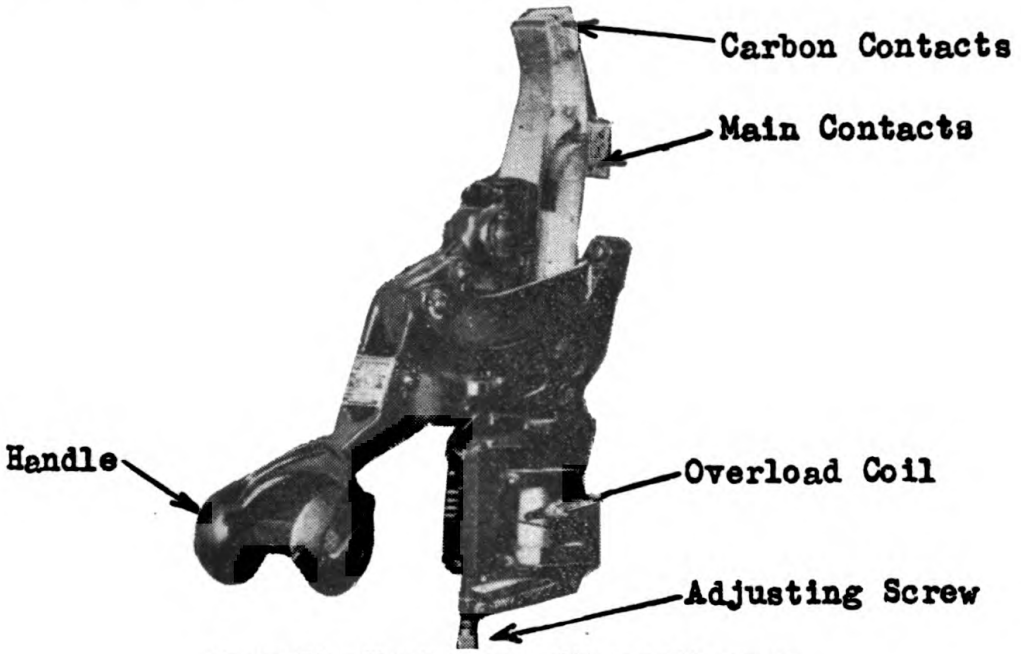


FIGURE 78.—Circuit breaker—600 to 1,200 ampere.

reset the circuit breaker. (See fig. 78.) In larger installations, instead of having all the load current flow through the tripping coil an overload relay is used to trip the circuit breaker.

j. In certain installations it is very important that the current does not reverse and flow in the wrong direction; for instance, where a generator is permanently connected to charge a battery and the speed of the generator is not constant, as is the case with the automobile and airplane battery charging generator. In this case if the speed drops off so the generator voltage is lower than the battery voltage, the battery will discharge through the generator causing it to run as a motor. This is undesirable, so a reverse current relay is connected in the circuit which will disconnect the circuit if current starts to flow

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in the wrong direction. Also in installations where two or more d. c. generators are connected in parallel, there is a reverse current relay incorporated in each generator's circuit. In case the voltage of one generator becomes a little less than the others and current starts to flow backward through this one generator, it will be disconnected from the line.

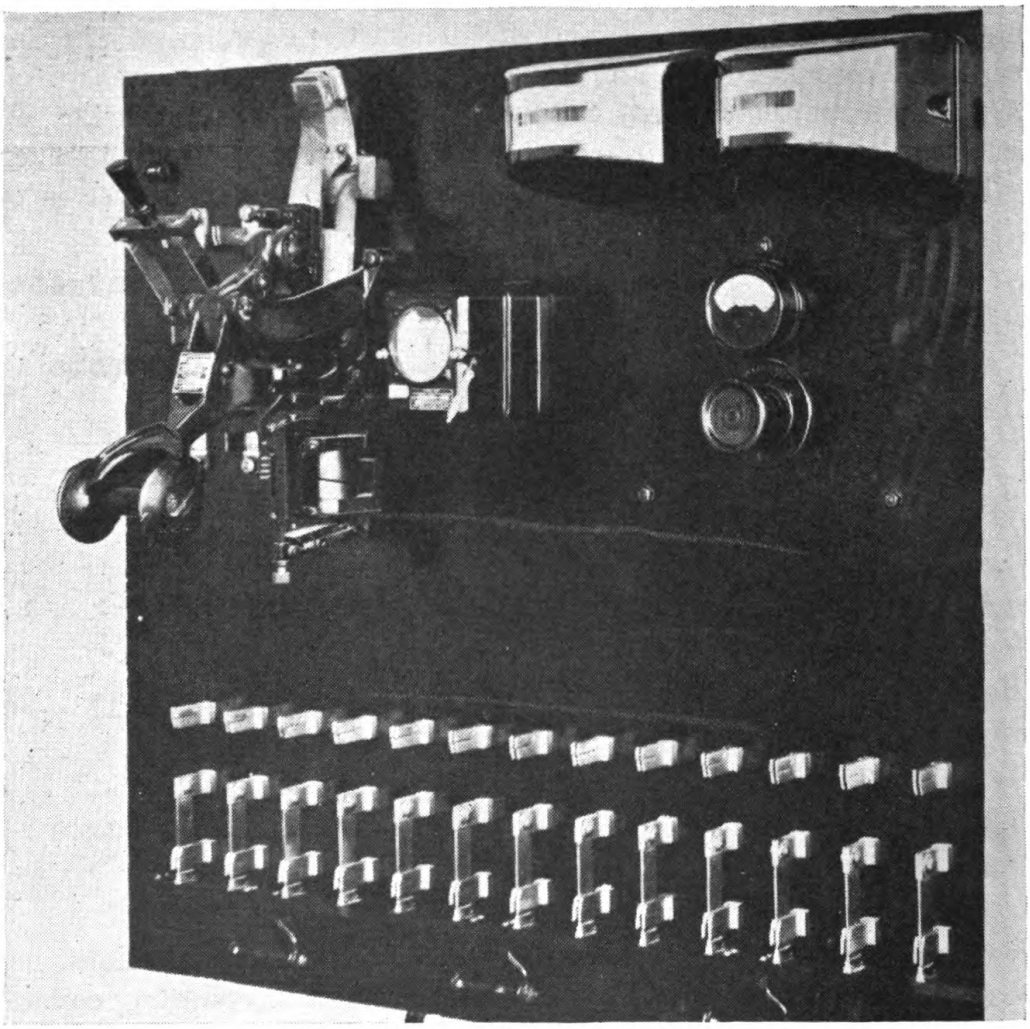


FIGURE 79.—Control panel.

k. Much of this control equipment is mounted on what is termed the control panel. These panels are usually upright and have the switches, relays, rheostats, contactors, and the various instruments, such as ammeters and voltmeters, in plain view of an operator who is charged with the care and maintenance of the equipment. Figure 79 shows a typical panel for a small installation of power equipment. This includes the control of a motor generator and a bank of Edison storage batteries. It enables the batteries to be charged in series and discharged in series-parallel.

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SECTION IX

ELECTRICAL MEASURING INSTRUMENTS

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Voltmeters	102
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99. General.—In operating, maintaining, and repairing electrical equipment and also in laboratory work, it is frequently necessary to measure one or more of the electrical quantities discussed in the previous sections. Efficiency is the watchword in modern industrial plants. From a practical viewpoint, the efficient operation of any installation is mainly a correct application of the laws of conservation and transformation of energy, and hence the operation cannot be efficient unless numerical data are available for determining the relation between energy generated or delivered and energy utilized by the various branches of the installation. To get these numerical data requires the use of proper and accurate instruments. The purpose of this section is to discuss briefly the types of electrical instruments used to measure current, voltage, power, resistance, etc. (See fig. 80.)

100. Meter movements.—*a.* Many instruments such as ammeters, voltmeters, wattmeters, and ohmmeters are of the indicating type; that is, the reading is obtained by noting the movement of a pointer across a calibrated scale. Other instruments such as wavemeters, frequency meters, and Wheatstone bridges are of the nonindicating type, and the reading is obtained by making the required adjustments and then noting the position of the dials, switches, etc., used in making these adjustments. The nonindicating instruments usually make use of an indicating instrument such as a galvanometer to tell the operator when the proper adjustments have been made. Other types of instruments known as recording instruments continually record values of voltage, current, power, etc., throughout the day on a sheet of graph paper which is moved along by a clock mechanism.

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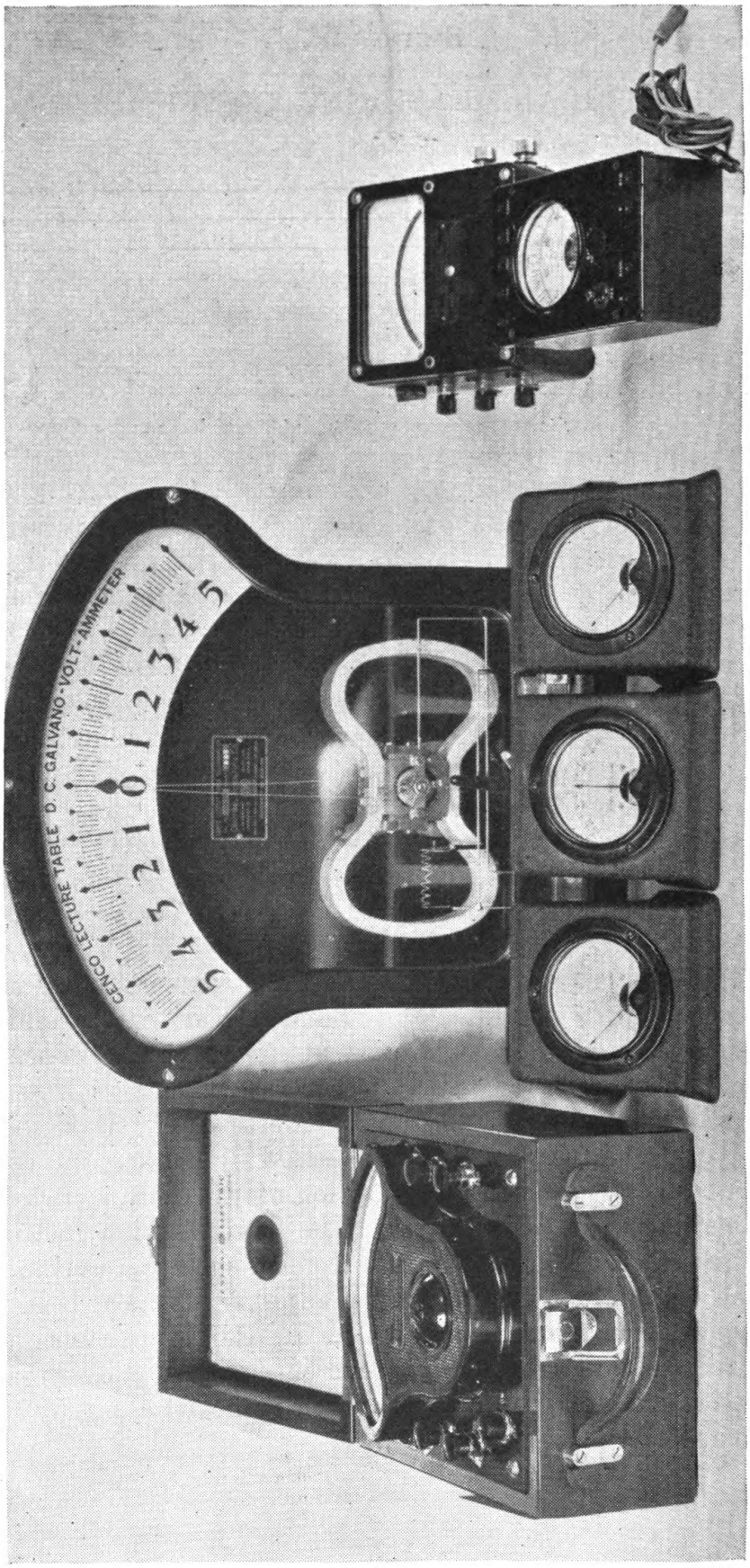


FIGURE 80.—Electrical measuring instruments.

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b. The fundamental unit of an indicating instrument that causes the pointer to move across the scale is called the meter movement. These movements may be classified into two broad groups, current movements and voltage movements. In the voltage movement the force or torque which moves the pointer across the scale against the retarding force of a spring is due to a dielectric field of force set up between two plates, one fixed and one movable with pointer attached. There are several types of dielectric or electrostatic meters on the market, but they are not used nearly as much as those employing current movements.

c. Current movements can be subdivided into two general classes: those in which the torque is due to the magnetic field and those in which the torque is due to the expansion of a conductor due to the heat produced by the current flowing through it. Most movements used other than in the laboratory are of the magnetic type. These magnetic movements are further divided into three general classifications. The one that is used extensively for d. c. and also with modifications for a. c. measurements is known as the Weston movement, after its inventor. The dynamometer and iron vane type instruments are used in connection with measuring low frequency alternating currents, voltage, and power. (See fig. 81.)

d. The Weston movement is also known as the permanent magnet moving coil type movement. Figure 82 shows the fundamental principle upon which the Weston movement is based. There is a permanent magnet with a small rectangular coil, suspended on jewel bearings, and free to rotate against the retarding force of two spiral springs. When an electric current passes through this coil it sets up a magnetic field about the coil which reacts with the magnetic field of the permanent magnet in such a way as to cause the coil, which has a pointer attached, to rotate. The amount of rotation will depend on the strength of the permanent magnet, the number of turns on the coil, the amount of current flowing through the coil, and also on the strength of the spiral springs. Modern Weston movements are carefully constructed so that the pointer's motion is directly proportional to the amount of current flowing through the coil.

e. The dynamometer movement is similar to the Weston movement except that instead of a permanent magnet it has an electromagnet whose field reacts with the field about the coil which is free to rotate and has a pointer attached to it. This type meter usually does not have a uniform scale.

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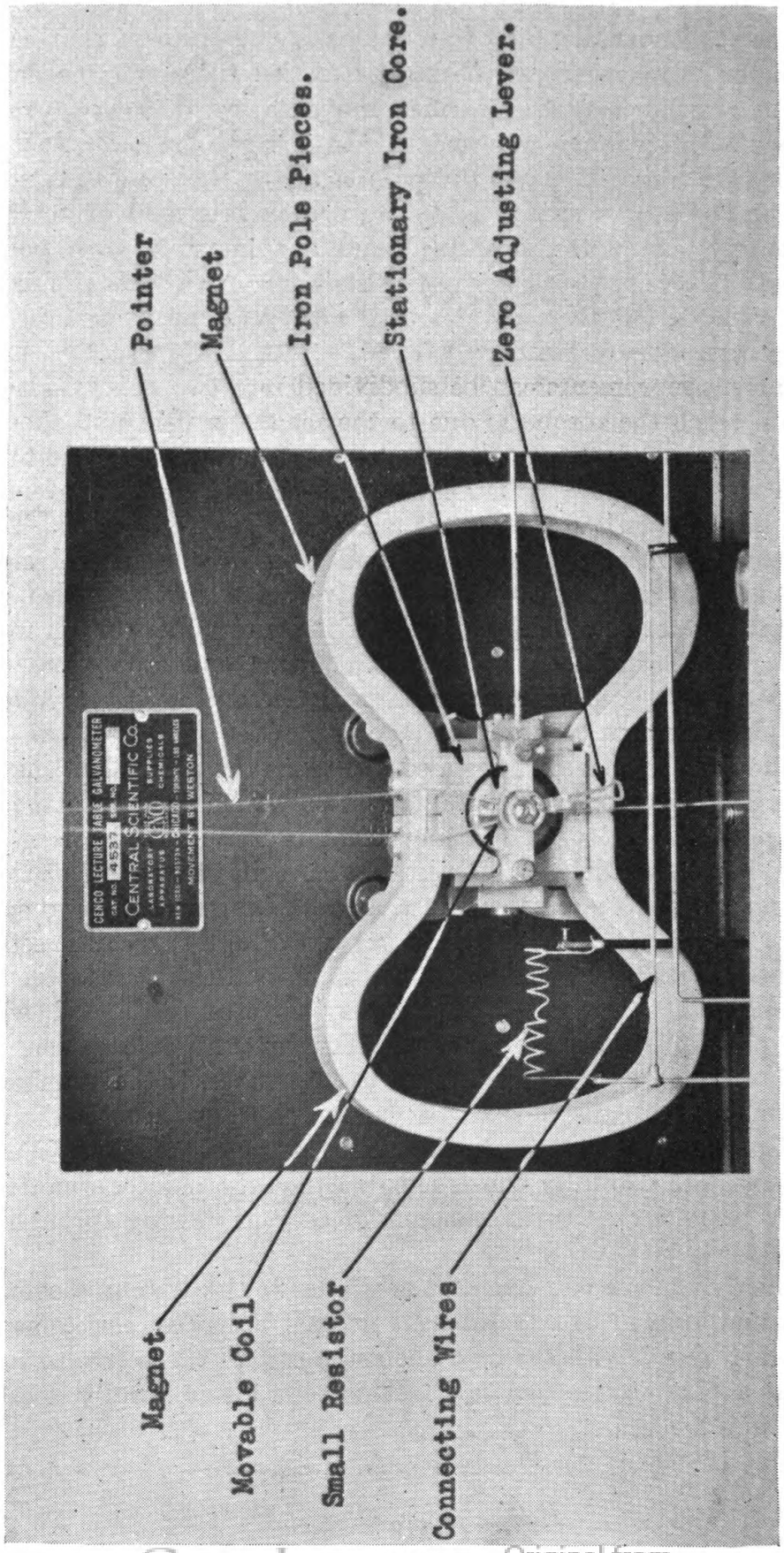


FIGURE 81.—Weston movement.

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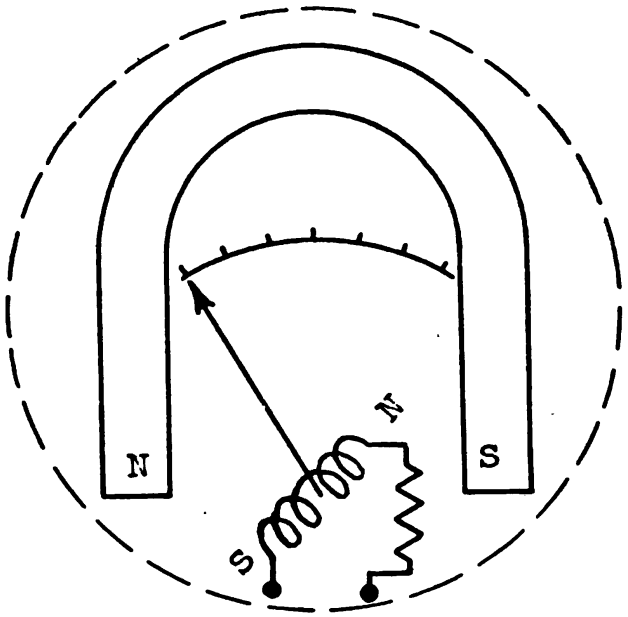


FIGURE 82.—Principle of Weston movement.

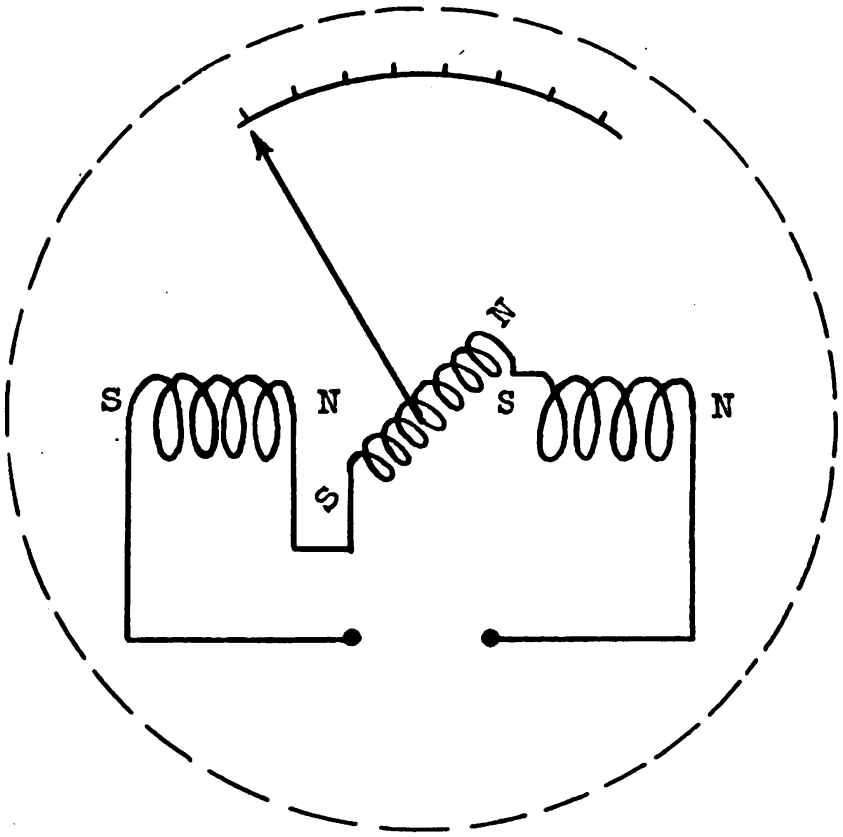


FIGURE 83.

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f. Figure 83 shows the fundamental dynamometer movement as it would be used in an ammeter or voltmeter.

g. The iron vane movement is constructed in various manners, but in any case the principle is approximately the same. One of the simplest forms of vane movement is merely a coil or solenoid with a movable iron plunger pivoted and associated with the coil in such a way that it will be pulled up inside the coil in proportion to the amount of current that flows through the coil. This meter movement also will have a nonuniform scale. Figure 84 represents a fundamental iron vane movement. Another type of movement has two iron vanes, one fixed and one movable with the pointer attached. These are both located inside the coil which carries the current or

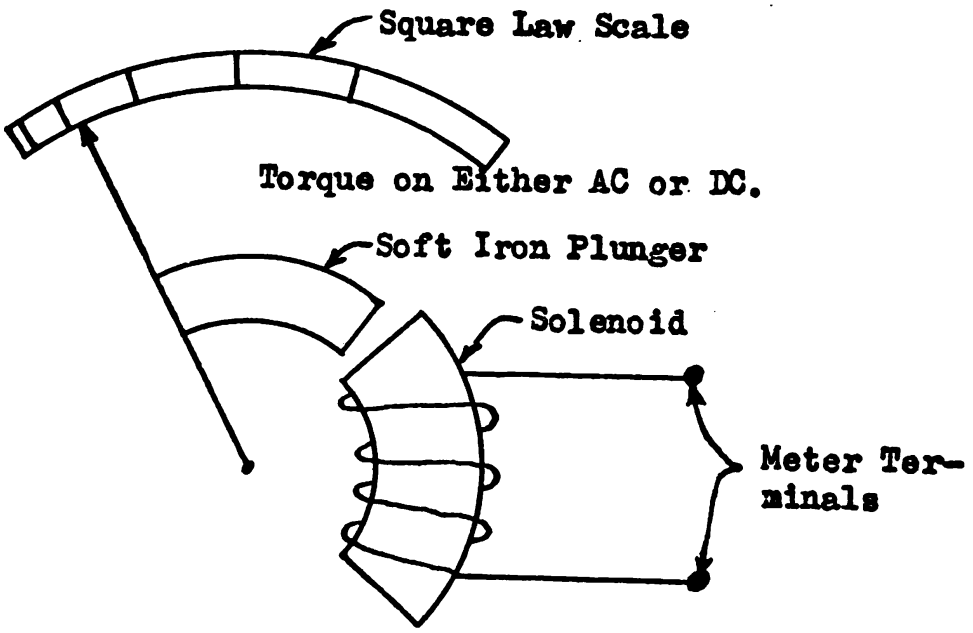


FIGURE 84.—Plunger type iron vane movement.

has the voltage applied which is to be measured. These two vanes when current flows through the coil will be magnetized in such a way as to repel each other. The amount of current flowing determines to what extent the movable vane which carries the pointer with it is deflected.

101. Milliammeters and ammeters.—*a.* Depending on the sensitivity, any of the above current movements can be calibrated directly in terms of milliamperes or amperes. Most Weston movements are very sensitive, using delicate springs, and the original movement must even be calibrated in microamperes. The dynamometer and vane movements are not nearly so sensitive as the Weston type movement.

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b. To extend the range of a current movement it is merely necessary to connect a resistance of suitable value in parallel or in shunt with the terminals of the movement. For this reason ammeters are usually milliammeter movements with shunts connected in parallel with them. To determine the resistance of a shunt, which is necessary to extend the range to the desired value, it is necessary to know the original current sensitivity of the movement and also the resistance of the movement. For instance, if it is desired to make a 0–1 ammeter from a Weston movement which requires but 5 milliamperes for full scale deflection, the resistance to be connected in parallel with this movement, then, the resistance of the shunt should be such that when 5 milliamperes flow through the meter movement, .995 ampere will flow through the shunt. To find the value of this resistance which would allow the current to divide in the above pro-

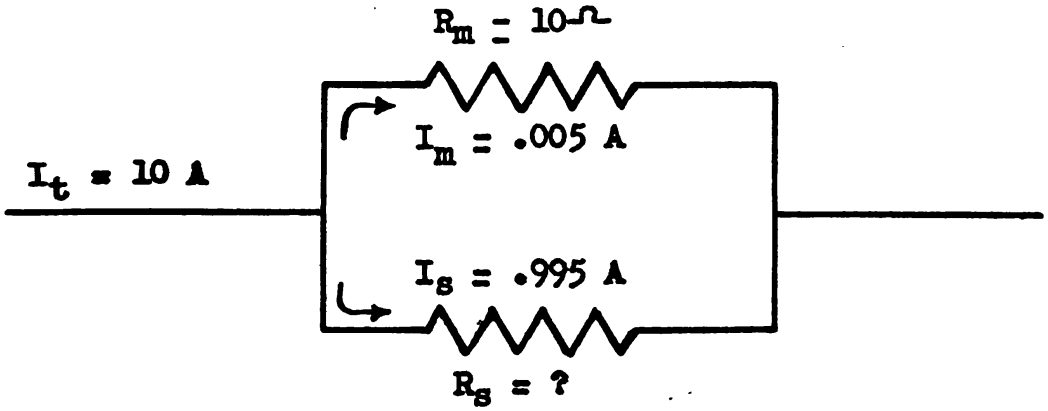


FIGURE 85.

portions, it is necessary to know the resistance of the meter movement. Suppose in the above case that the resistance of the movement was 10 ohms. Then to find the value of shunt resistance it would be necessary to solve the following parallel circuit problem. (See fig. 85.) Referring to the methods for solving parallel circuit problems which were given in a previous section, it will be seen that the resistance of the shunt which is necessary to provide a current division as indicated will be 0.0502+ ohm.

c. The range of any current movement or any milliammeter or ammeter that has already been calibrated can be extended by the above procedure.

102. Voltmeters.—*a.* The main difference between voltmeters and ammeters lies in their use. Ammeters are connected in series with the circuit in which the current is to be measured; that is, they are con-

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nected in such a way that the total or a proportional part of the total current passes through the instrument. Voltmeters, on the other hand, are connected in parallel with the circuit; that is, the terminals of the voltmeter are connected to two points between which the difference of potential or voltage is to be measured. Figure 86 shows these methods of connecting voltmeters and ammeters in a circuit. Since the current in a circuit should be the same after the ammeter is inserted in series to measure it as it was before the meter was put there, it can be seen that ammeters should have a low resistance between terminals. On the other hand, since voltmeters are connected across or in parallel with the circuit, they must have a very high resistance so that the small amount of current they take will not disturb the conditions of the circuit. The voltage of a circuit should be the same after a voltmeter is placed across the circuit as it was before. If the voltmeter does not have a high resistance this will not be the case.

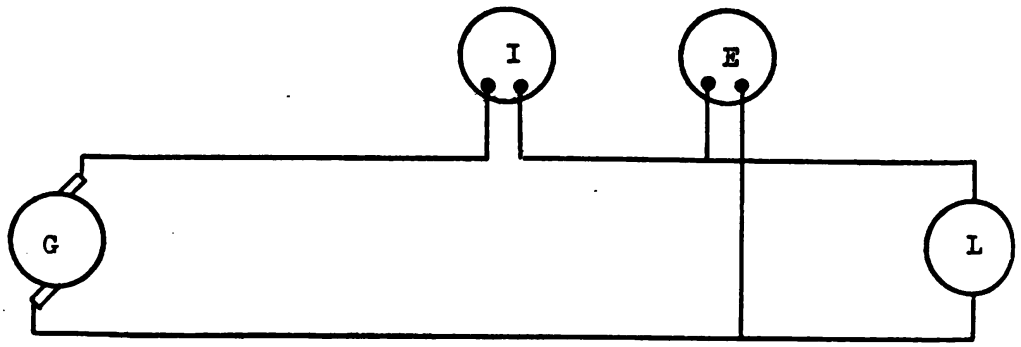


FIGURE 86.

Under certain conditions, especially in connection with radio and communication work, the currents flowing in the circuit may be less than the currents that ordinarily low resistance voltmeters require to actuate them. The principle underlying the fundamental operation of voltmeters and current meters using the above current movements is the same with the exception that the resistance between terminals of the voltmeters must be much higher. This can be accomplished either by winding the coil which carries the current out of very fine resistance wire, or as is usually the case in practice, an ordinary standard current movement is used with the addition of a resistor connected in series. Figure 87 shows a Weston movement connected as a voltmeter.

b. To find the size resistance necessary to make a certain range voltmeter it is merely necessary to apply Ohm's law. In other words, $R=\frac{E}{I}$ where E is the voltage range to be measured and I is the full scale current of the movement. Suppose it is desired to construct a

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0-50 voltmeter from a Weston movement which has a full scale current requirement of 1 milliampere and a resistance of 30 ohms. From Ohm's law, $E=IR$, it can be seen that this current movement could be used to measure voltages up to 0.03 of a volt, since this amount of voltage would be required to force 1 milliampere of current through the 30 ohms resistance which the movement has. To extend the range of this meter so that it would measure 50 volts would require that the resistance be much greater than 30 ohms. To find just how much greater the resistance should be, one of two methods could be used. Considering that the meter "as is" will measure 0.03 of a volt, then in

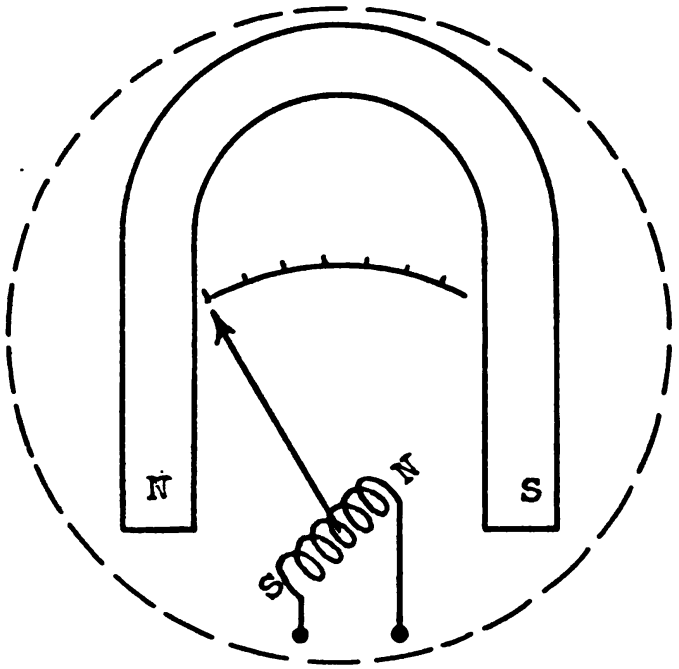


FIGURE 87.

order for it to measure 50 volts the resistance will need to be $\frac{50}{0.03\times 30 \text{ ohms}}=50{,}000$ ohms. In other words, the ratio of the resistances will be the same as the ratio of the voltages since the current in each case is the same. Another method is to use Ohm's law throughout. From Ohm's law, $R=\frac{E}{I}$, the total resistance necessary for a 50-volt voltmeter is $\frac{50}{0.001}=50{,}000$ ohms. Since the meter already has 30 ohms, it is merely necessary to subtract this 30 from the value which is obtained. In many cases, such as the above, it is not necessary to subtract the original resistance of the movement since it is such a

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small percentage of the total resistance required that it can be neglected. The resistance used to extend the range of a voltmeter is usually referred to as a multiplier resistance. Some voltmeters have the multiplier resistance connected internally as a permanent part of the meter movement. Others have marked on the scale "multiplier external," and in this case the person using the instrument must be sure to obtain the proper multiplier resistance and connect it in series with the meter movement proper before using it to measure voltage.

103. Ohmmeters.—*a.* The same movement that was used to measure various size currents and voltages can also be used to measure resistance. In this case the instrument is called an ohmmeter. Since a movement cannot be made without having a certain amount of resistance, it can be calibrated in either current or voltage using Ohm's law as a basis of the calibration. If, in addition to the move-

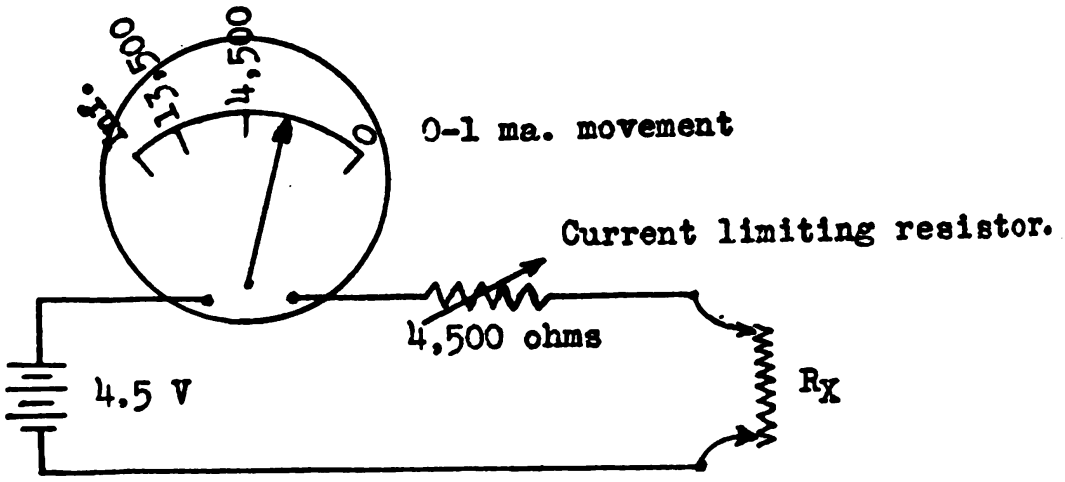


FIGURE 88.—Series ohmmeter with current limiting resistor.

ment, a source of e. m. f. is included, the movement can be calibrated in ohms from the formula, $R_x=\frac{E}{I}-R_m$; E being the voltage of the small battery used and I the current indication of the movement when the terminals are placed across the resistance to be measured, R_x. (See fig. 88.) Notice that in addition to the movement and the battery a variable resistor is also employed. This resistance would not be necessary if a fixed and constant voltage of exactly the right value could be obtained. Since this is not the case, a variable resistor is incorporated so that when the test prods of the ohmmeter are shorted together (i. e., connected across zero resistance), the meter movement will show full scale deflection. The reason this resistor is made variable is to compensate for the fact that the battery voltage

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will gradually get less as the battery becomes older from continued use. Instead of replacing the battery, when the voltage drops off slightly, the variable resistor can be adjusted so that any time the prods are connected to zero resistance the meter will indicate exactly full scale. Full scale on the ohmmeter is marked zero ohms because that is the value of resistance which is between the test prods when the pointer of the movement points to full scale deflection. On the other hand, if the test prods are held apart such that in effect they are measuring the resistance of the air which for all practical purposes can be considered to be infinite, the meter movement's pointer will remain at zero current or no deflection. This point on the scale of an ohmmeter is marked "infinite resistance." The various points between these two values (i. e., zero and infinite) will be marked to correspond to various values of resistance. Although the theoretical range of the ohmmeter is from zero to infinity, the practical readable range is far from being this great. An ohmmeter which is constructed by inserting a 4½-volt battery in series with a current limiting resistor and a 0–1 milliammeter will have a readable range from about 100 ohms to possibly 20,000 ohms.

b. The fundamental range of the above practical ohmmeter can be extended in either direction. To extend the range so that the meter will be capable of reading higher values of resistance, it is either necessary to use a higher voltage or a more sensitive movement. In either case a larger current limiting resistance will be necessary. To enable the ohmmeter to read lower values of resistance, a shunt is usually connected across the movement and current limiting resistor. Many practical ohmmeters have several resistance ranges which are selected by throwing a switch or plugging the test prod leads into various jacks.

104. Sensitivity of meters.—*a.* In general, the word "sensitivity" when applied to meters means the same as when applied to any other thing. In other words, a sensitive current movement will measure very small values of current, while an insensitive current movement requires much larger values of current to give a corresponding deflection of the pointer. In connection with current meters the sensitivity is defined as the amount of current required for full-scale deflection. Hence, the sensitivity of a 0–1 milliammeter is 1 milliampere or the sensitivity of a 0–25 milliammeter is 25 milliamperes. Weston movements have been made as sensitive as 10 microamperes.

b. An exception to the above rule is where sensitivity is used in connection with voltmeters. A sensitive voltmeter does not mean that it will measure very small voltages. A 0–1,000 voltmeter may be just as sensitive or even more sensitive than a 0–1 voltmeter. Sensitivity in

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connection with voltmeters is measured in terms of the resistance per volt which can be measured with the instrument, hence, the term "ohms per volt." From this explanation it can be seen that the sensitive voltmeter is the high resistance voltmeter. The term "high resistance voltmeter" is in common use but does not always mean a high total resistance, but instead it means a high resistance per volt of scale.

c. The dynamometer and iron vane movements are relatively insensitive as compared to the Weston movement.

105. Rectifier type meters.—*a.* The Weston movement, although a very sensitive instrument, is not suitable for measuring alternating current, as can be seen from examining the fundamental circuit shown by figure 82. When the current reverses, the direction of the rotating force is also reversed. For this reason if alternating current is applied to a Weston movement the pointer will tend to vibrate back and forth about the zero position at the applied frequency. For frequencies used in practice, such as 60 cycles per second, it would be impossible mechanically for the pointer to follow these alternations. For this reason, when applied to alternating current, the Weston movement does not indicate. Although the dynamometer and iron vane movements are suitable for either direct or alternating current, due to their insensitivity they are not suitable for certain applications. A rectifier in connection with the Weston movement overcomes these disadvantages. A rectifier is a device for changing alternating current into direct current. In other words, it is a device that will allow current to flow in one direction but not in the other. Rectifiers are of various types, but the ones used to the greatest extent in connection with a. c. meters are of the copper oxide type. It has been found that a contact of copper and copper oxide under favorable conditions offers a much higher resistance to the flow of current in one direction than in the other. Figure 89 indicates a copper oxide rectifier inserted in series with an a. c. circuit.

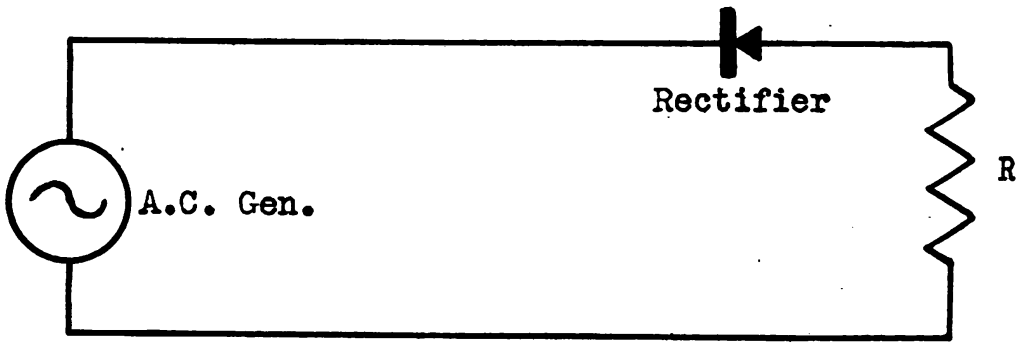
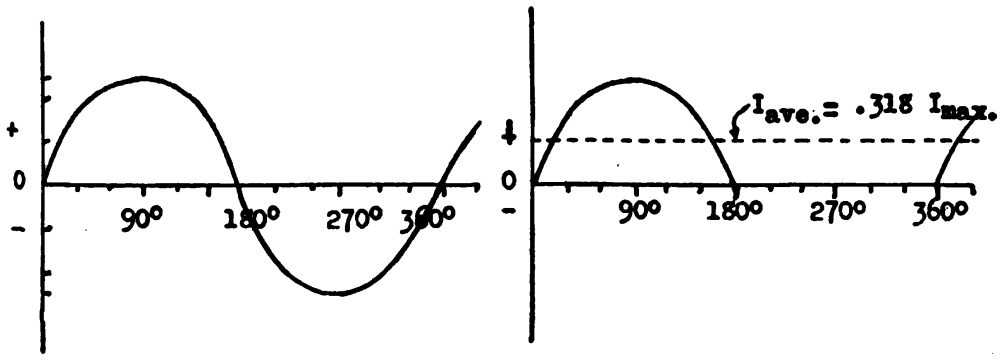


FIGURE 89.

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b. The a. c. wave before and after the rectifier was inserted in the circuit is shown in figure 90. Note that in this case only the positive alterations were passed. By the use of two or more rectifiers in a suitable circuit, the negative alternation is merely reversed and caused to flow in the same direction as the positive alternation. (See fig. 91.)



① Original current. ② Half-wave rectification.

FIGURE 90.

This latter method is called full wave rectification. The most efficient method of obtaining full wave rectification for use in rectifier type meters is by the use of four half-wave rectifiers connected in a bridge circuit. (See fig. 92.)

c. During one alternation the electrons are flowing in the line from left to right. The rectifiers allow them to flow from the copper

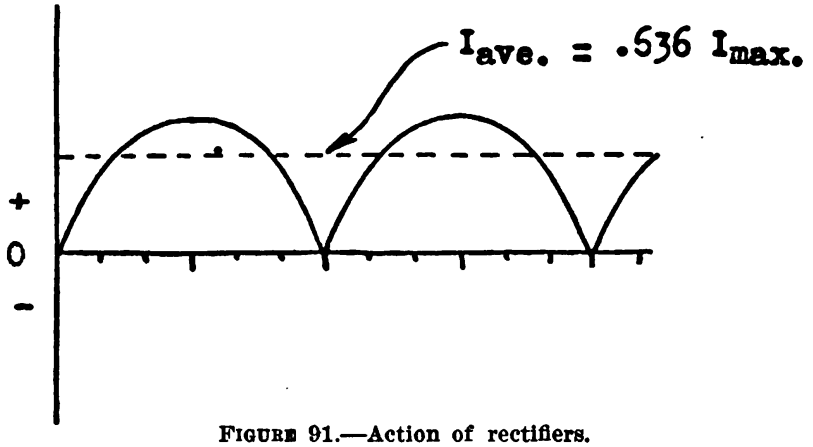


FIGURE 91.—Action of rectifiers.

(dark arrow) to the copper oxide but not from the copper oxide to the copper. This causes the electrons flowing from left to flow through rectifier No. 1, up through the meter movement, and through rectifier No. 3 to the line connected to the right side of the circuit. During the next half cycle, the electrons flow from right to left in the line and are forced to pass through rectifier No. 2, up through the

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movement and back to the line through rectifier No. 4. This results in a current flow through the meter of the wave form shown in figure 91.

d. The entire rectifier is "layer built" of copper and copper oxide washers placed on a bolt and clamped together along with suitable terminal washers for making connections to the unit and lead washers

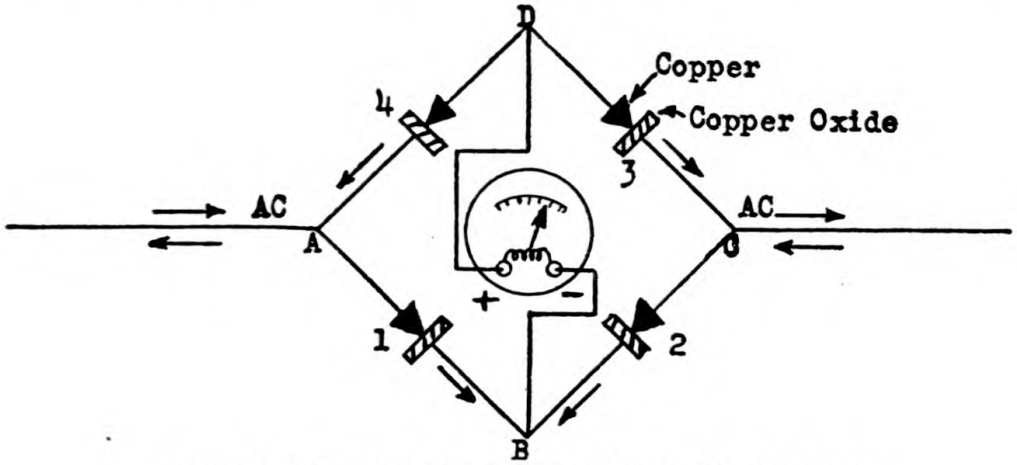


FIGURE 92.—Rectifier bridge circuit used in rectifier type meter.

for insuring that good contact is made between rectifier washers and terminals. All washers are, of course, insulated from the bolt on which they are mounted. Figure 93 shows the actual physical construction of a rectifier. The numbers and letters on the rectifier unit correspond to similar numbers and letters on the bridge circuit of figure 92. Thus, terminals D and B would be connected to the

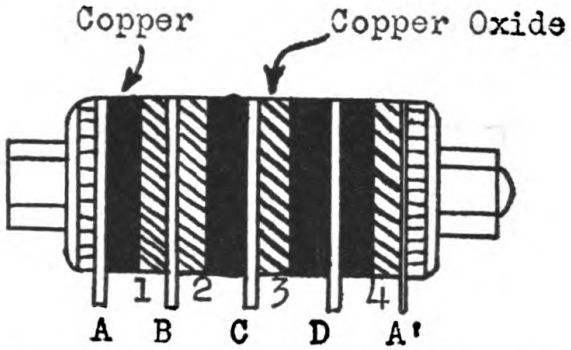


FIGURE 93.—Copper oxide meter rectifier unit.

(+) and (−) terminals of the meter movement, respectively. One line connection would be made to terminals A and A′ and the other would be made to terminal C.

e. The range of a rectifier type meter may be extended in the same way as the range of any of the meters previously discussed, that is,

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by the use of shunts or multipliers. The shunt for a rectifier type instrument must be connected in parallel with the rectifier and the movement so that only the current flowing through the movement flows through the rectifier. The rectifiers are designed for approximately the same current rating as the meter movements with which they are to be used. Thus, if the shunt were connected across the meter movement only, the entire line current would flow through the rectifier and ruin it.

f. When a sine wave of current is passed through a Weston type d. c. meter connected in a copper oxide rectifier bridge circuit, every reading on the d. c. scale must be multiplied by 1.11 to give the effective value of the alternating current present. The Weston movement's deflection is proportional to the average current. The ratio of the effective and average for a sine curve is $\frac{0.707}{0.636}=1.11$. A new scale could be made which would read directly in effective value of sine wave alternating current and which would also be a uniform scale. Indeed, this is the type scale placed on the rectifier type meters in the factory so that although the indication is proportional to the average current through the movement, the readings are obtained in effective values.

g. A rectifier type meter will indicate correctly only when used on sine wave alternating current. A current wave more flat than a sine wave will have a ratio $\frac{I_{Eff}}{I_{Ave}}$ of less than 1.11, and hence a rectifier meter in such a circuit will read too large a value. Similarly, when the wave of current is more peaked than a sine wave, the ratio of effective to average value is greater than 1.11 and therefore the rectifier meter will read too small a value. When the rectifier meter is connected in a circuit containing direct current, the rectifiers will act to make this current pass through the meter movement regardless of the way in which the meter is connected in the circuit. The indication, then, will be proportional to the value of current flowing. However, since the meter is calibrated for sine wave alternating current (all points on the d. c. scale have been multiplied by the factor 1.11) the reading will be too large.

h. The rectifier type meter may be used at any frequency up to 20,000 to 30,000 cycles per second with a fair degree of accuracy. During the part of a cycle that a copper oxide rectifier does not carry current it acts as a condenser due to the potential difference between the copper and the copper oxide. This results in a capacitive current during this half cycle that increases directly with the frequency. Thus less current is left to flow through the meter movement. This capacitive

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action results in a decrease of the meter reading of from ½ percent to 1 percent for each 1,000 cycles per second increase in frequency up to about 35,000 cycles per second. At extremely high frequencies, such as are used in radio, practically the entire current would flow through the rectifiers due to this action, and the resulting indication on the meter would be very small and inaccurate.

106. Thermocouple type meters.—*a.* Another type meter has been developed primarily to measure high frequency currents encountered in communication work. This is the thermocouple type meter which also makes use of the highly sensitive Weston movement but in a different way from the rectifier type.

b. When two pieces of wire of dissimilar metal are connected together at one end and the junction heated, it will be found that a d. c. voltage is developed between the open ends of the wires. The voltage will be directly proportional to the temperature difference between the connected and unconnected ends. For the same temperature difference, different combinations of metals will give different voltages. This generation of a d. c. voltage by heating the junction of two dissimilar metals is known as electrothermal action, and the device that permits this action to take place is known as a thermocouple.

c. If the unconnected ends of the wires making up a thermocouple are connected to a Weston meter movement, a d. c. current will flow through the movement which is directly proportional to the difference between the temperature of the thermocouple junction and the room temperature and inversely proportional to the resistance of the circuit, including the meter movement, the thermocouple, and the connecting wires in series.

d. Such a meter, including thermocouple and movement, could be, and frequently is, calibrated directly in degrees of temperature, and when so calibrated the scale is uniform. A device of this kind is called a pyrometer. The heating effect of current can be used to make this thermocouple type meter indicate by passing the current to be measured across the thermocouple junction but not through the meter movement. This results in a heating of the junction and consequently a temperature increase which is proportional to I^2. Since the current through the movement is proportional to the temperature difference between the thermocouple and the movement (room temperature), it will increase as the square of the current flowing in the external circuit. Hence, such a meter, when calibrated in current flowing in the external circuit, will have a square law scale, i. e., nonuniform. Figure 94 shows the fundamental thermocouple milliammeter.

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e. The direction of external current flow will have no effect on the direction of current through the movement of a thermocouple type meter; therefore it can be used to measure either direct or alternating current. The impedance of the thermocouple is practically pure resistance and essentially constant for all frequencies, and therefore the meter will indicate accurately on extremely high frequency currents, something that no other meter previously mentioned, except the hot wire meter, will do.

f. The sensitivity of the thermocouple type meter is determined by the sensitivity of the movement used and also by the materials of which the thermocouple is made. The greatest voltage is generated per degree of temperature difference by a thermocouple made of bismuth and antimony. For this reason, one wire made of an alloy of bismuth and one made of an alloy of antimony are used to make the thermocouple

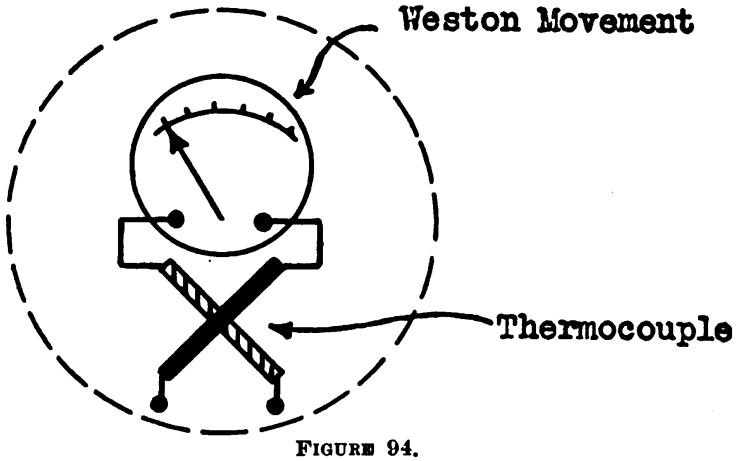


FIGURE 94.

for use in a thermocouple type meter. This results in a highly sensitive meter when used with a sensitive meter movement.

107. Wattmeters.—*a.* The instrument which is usually used for measuring power is called a wattmeter. Wattmeters are of various types, but the one usually encountered works on the dynamometer principle. The dynamometer movement used in a wattmeter is similar to the dynamometer ammeter or voltmeter movement with the exception that instead of having the movable and fixed coils connected in series, they are entirely separate circuits.

b. Since power is equal to *EI*, if one of the coils of a dynamometer movement is inserted in series with the circuit such that the magnetic field will be proportional to the current flowing, and the other coil is connected in parallel with the circuit such that the field about it will be proportional to the voltage, the resulting torque due to the action of these magnetic fields on each other will be proportional to the power

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and hence the scale can be calibrated in watts. Figure 95 indicates a wattmeter connected in a circuit. As with ammeters, the current coil of a wattmeter should have low resistance and be able to carry the line current without becoming excessively hot. For this reason it is wound with a few turns of heavy wire and is made the stationary coil. The potential or voltage coil of a wattmeter, similar to a voltmeter, must have high resistance and either be wound from a large number of turns of fine wire or, as is the case of the voltmeter, have a resistance connected in series with it. The voltage coil of a wattmeter is the moving coil and has the pointer attached to it. The dynamometer wattmeter is suitable for measuring power in either d. c. or a. c. circuits. In the case of a. c. circuits, the wattmeter gives the true I^2R value of power regardless of the phase angle between the voltage and current. By examining figure 96, which indicates the power in d. c. and a. c. circuits under various phase relations, it can be seen why the

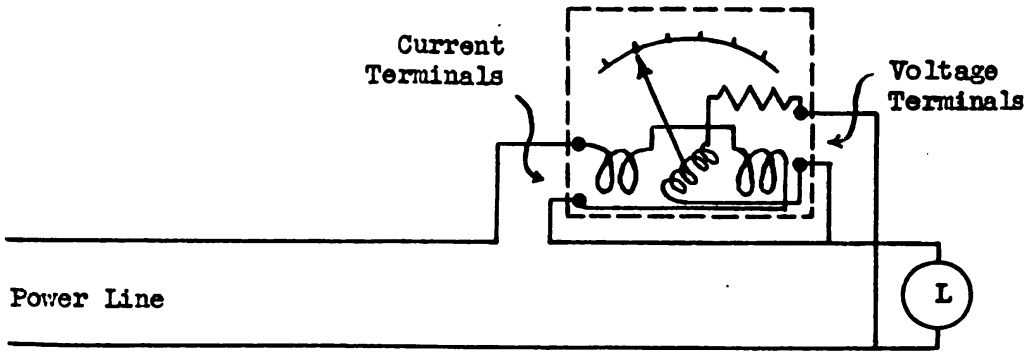


FIGURE 95.

dynamometer type wattmeter indicates true power instead of apparent power.

Note in figure 96 ③ and ④ that some of the power is indicated graphically below the zero axis. During this period of the cycle, due to the fact that the voltage is in one direction at the same time the current is in the opposite direction, the effect on the wattmeter pointer is to tend to pull it backward. But due to the high frequency the wattmeter pointer does not follow the fluctuations but merely settles down to the average value of power over a complete cycle. In figure 96 ③, since the wattmeter pointer is being pulled backward for the same length of time that it is being pulled forward, the net average power in a circuit similar to this with voltage and current 90° out of phase will be zero. In figure 96 ④ the negative power is much less than the positive power, hence the wattmeter will indicate a positive reading, but it will not be as much as the reading shown at figure 96 ② where the voltage and current are in phase.

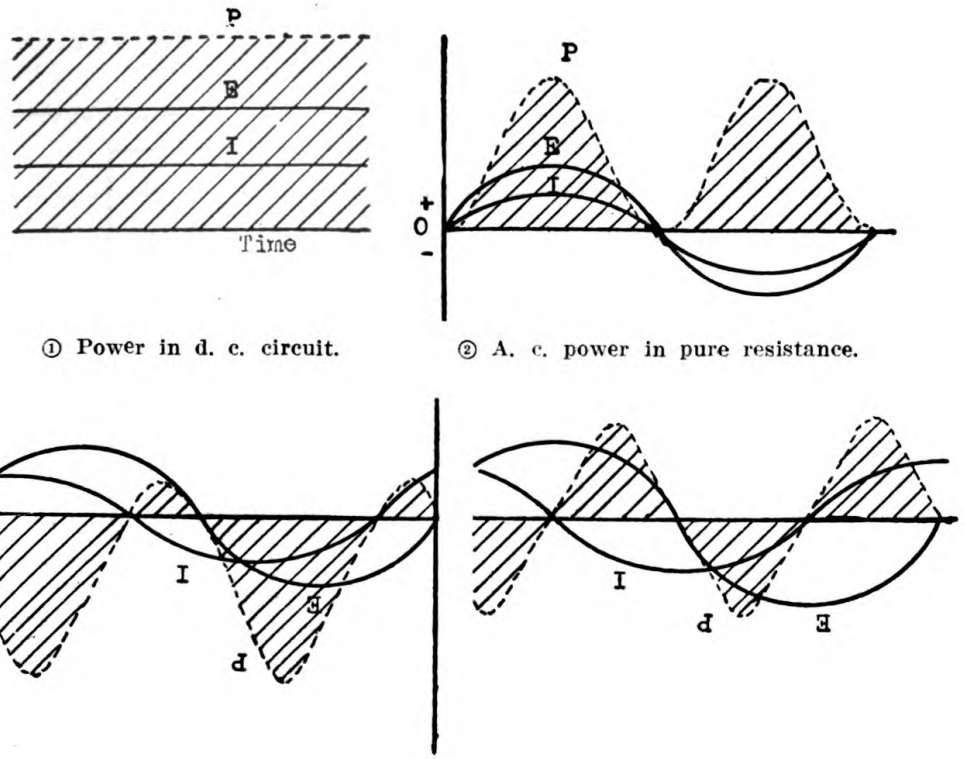
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108. Combination instruments.—*a.* Since it has been shown that the same meter movement can be used for measuring various electrical quantities, it is a simple matter to combine shunts and multipliers to give various ranges of volts and amperes from the same instrument. An instrument of this kind is called a volt-ammeter.

b. The volt-ohmmeter is another example of a combination instrument. Multirange volt-ohmmeters can be included in a pocket-size case and are used extensively by radio service men.

c. Many times a combination instrument, including a Weston movement with several scales, is incorporated in the same case with the shunts, multipliers, resistors, rectifier units, and selector switch for enabling various ranges of a. c. or d. c. voltage, milliamperes, and resistance to be measured.

d. Figures 97 and 98 show typical circuits of combination instruments.



① Power in d. c. circuit.

② A. c. power in pure resistance.

③ Power with E and I 90° out of phase.

④ Power with E and I less than 90° out of phase.

FIGURE 96.—Power curves.

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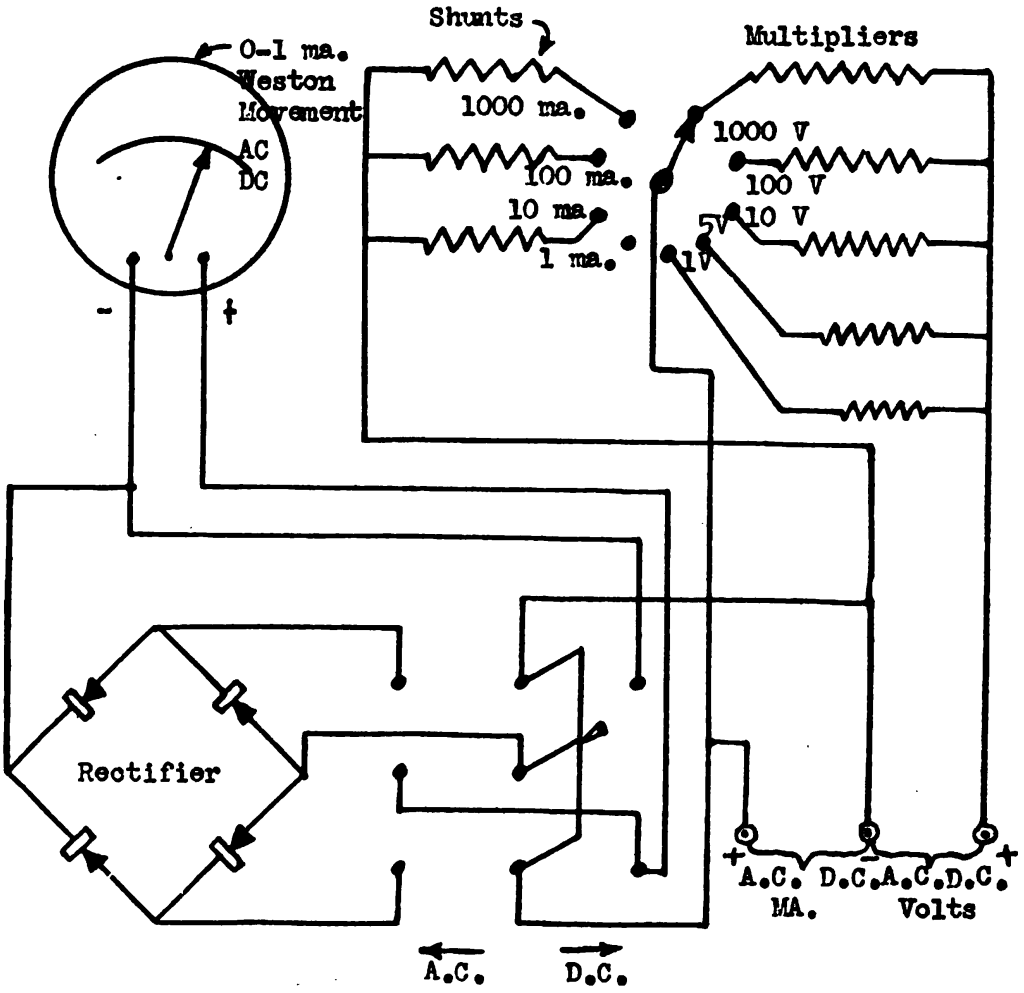


FIGURE 97.—Combination a. c. and d. c. volt-milliammeter.

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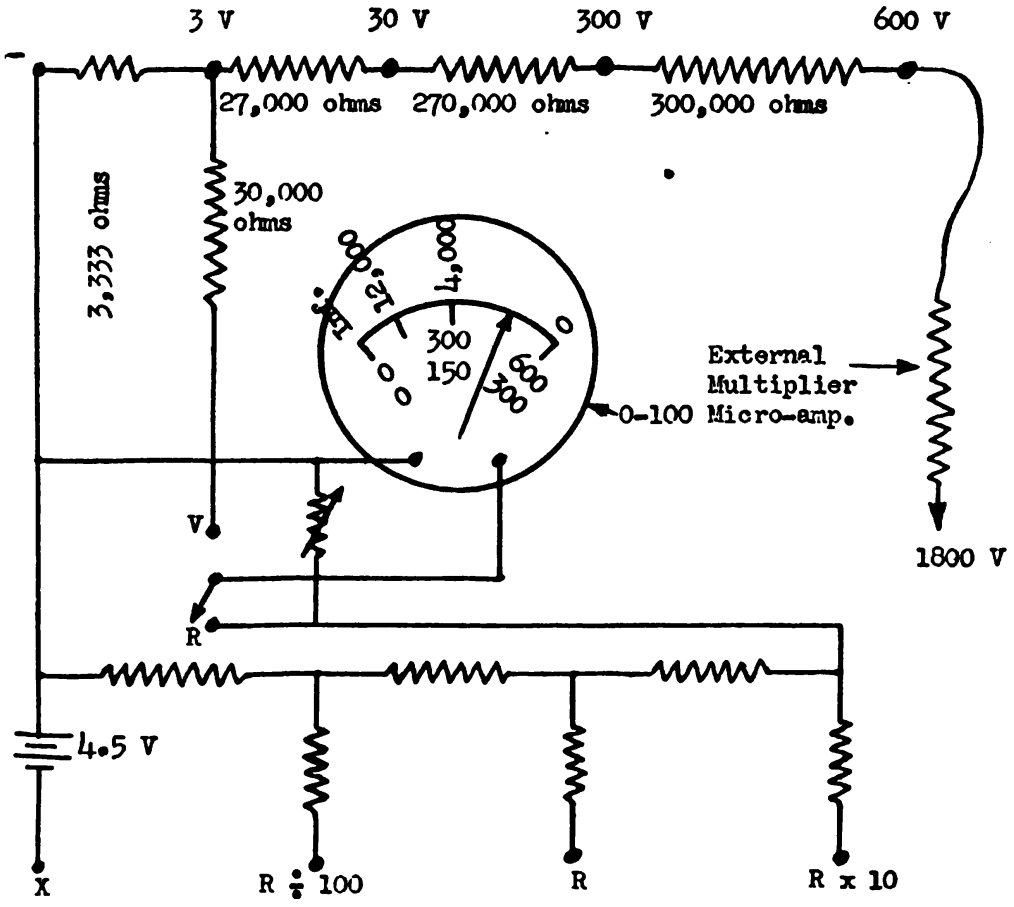


FIGURE 98.—Weston M564-3B volt-ohmmeter.

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APPENDIX I

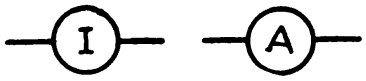
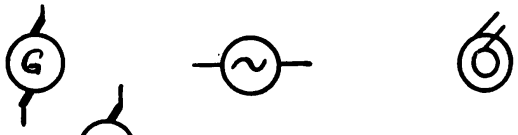
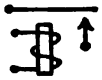
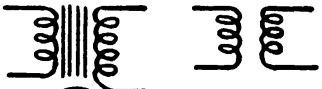
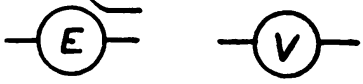
ELECTRICAL SYMBOLS

Symbols of electrical quantities.

Name	*Symbol or abbreviation*
Alternating current	a. c. or A. C.
Ampere	A or I
Ampere turn	A. T.
Angle	∠
Apparent power	V. A. or K. V. A.
Average value	E_{av} and I_{av}
Capacitance	C
Capacitive reactance	X_C
Conductance	G
Coulomb	q or q′
Current	I
Cycle	~
Direct current	d. c. or D. C.
Effective value	E_{eff} and I_{eff}
Electromotive force	E. M. F. or e. m. f.
Force	F
Frequency	f
Impedance	Z
Inductance	L
Inductive reactance	X_L
Kilowatt	KW
Magnetic pole strength	M and M′
Magnetomotive force	M. M. F.
Maximum value	E_m and I_m
Megohm	Meg.
Microfarad	Mf. or Mfd.
Milliampere	Ma.
Ohm	Ω
Permeability	μ
Potential difference	P. D.
Power	P or W
Resistance	R
Speed	R. P. M.
Volt	V or E
Watt	W

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Schematic electric symbols.

Name	*Symbol*
Ammeter	
Battery	
Circuit breaker	
Condenser	
Contactor	
Electromagnet	
Fuse	
Generator	
Motor	
Rectifier	
Relay	
Rheostat	
Switches	
Transformer	
Voltmeter	
Wattmeter	

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Appendix II

SUMMARY OF FORMULAS

$I=\frac{E}{R}$ (for d. c. circuits)

$I=\frac{E}{Z}$ (for a. c. circuits)

$I_t=I_1+I_2+I_3+$etc. (parallel d. c. circuits)

$I=\frac{E}{X_L}$ (pure inductive circuits)

$I=\frac{E}{X_C}$ (pure capacitive circuits)

$E=IR$ (for d. c. circuits)

$E=IZ$ (for a. c. circuits)

$E=IX_L$ (inductive circuits)

$E=IX_C$ (capacitive circuits)

$E_t=E_1+E_2+E_3+$etc. (series circuits)

$R=\frac{E}{I}$ (for d. c. circuits)

$R_t=R_1+R_2+R_3+$etc. (for series circuits)

$R_t=\frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\text{etc.}}$ (parallel circuits)

$R_t=NR$ (in case of N equal resistors in series)

$R_t=\frac{R}{N}$ (in case of N equal resistors in parallel)

$R=\frac{1}{G}$

$G=\frac{1}{R}$

$R=\frac{kL}{S}$ (where L is the length, S is the cross section area, and k is a constant)

$C=Q/E$

$C_t=C_1+C_2+C_3+$etc. (condensers in parallel)

$C_t=\frac{1}{\frac{1}{C}+\frac{1}{C}+\frac{1}{C}+\text{etc.}}$ (condensers in series)

$L_t=L_1+L_2+2M$ (inductors in series)

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$$L_t=\frac{1}{\frac{1}{L_1\pm M}+\frac{1}{L_2\pm M}}\text{ (inductors in parallel)}$$

$$X_L=2\pi fL$$

$$X_C=\frac{1}{2\pi fC}$$

$$Z=\sqrt{R^2+X_L{}^2}\text{ (inductive circuits)}$$

$$Z=\sqrt{R^2+X_C{}^2}\text{ (capacitive circuits)}$$

$$W=EI\text{ (for d. c. circuits)}$$

$$W=I^2R\text{ (any type of circuit)}$$

$$W=\frac{E^2}{R}\text{(d. c. circuits)}$$

$$W_t=W_1+W_2+W_3+\text{etc.}$$

$$F=\frac{mm'}{d^2}$$

$$F=\frac{qq'}{d^2}$$

$$f=\frac{\text{Number of poles}}{2}\times\frac{\text{speed in R. P. M.}}{60}\text{ (frequency generated by rotating machinery)}$$

$$\frac{E_p}{E_s}=\frac{T_p}{T_s}\text{ (providing coupling is unity)}$$

$$\frac{I_p}{I_s}=\frac{T_s}{T_p}\text{ (providing coupling is unity)}$$

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Appendix III

MATHEMATICAL TABLE OF SQUARES AND SQUARE ROOTS

n	n^2	$\sqrt{n}$	n	n^2	$\sqrt{n}$	n	n^2	$\sqrt{n}$
1	1	1.	41	1681	6. 4031	81	6561	9. 0000
2	4	1. 414	42	1764	6. 4807	82	6724	9. 0554
3	9	1. 732	43	1849	6. 5574	83	6889	9. 1104
4	16	2. 000	44	1936	6. 6332	84	7056	9. 1652
5	25	2. 236	45	2025	6. 7082	85	7225	9. 2195
6	36	2. 449	46	2116	6. 7823	86	7396	9. 2736
7	49	2. 646	47	2209	6. 8557	87	7569	9. 3274
8	64	2. 828	48	2304	6. 9282	88	7744	9. 3808
9	81	3. 000	49	2401	7. 0000	89	7921	9. 4340
10	100	3. 162	50	2500	7. 0711	90	8100	9. 4868
11	121	3. 3166	51	2601	7. 1414	91	8281	9. 5394
12	144	3. 4641	52	2704	7. 2111	92	8464	9. 5917
13	169	3. 6056	53	2809	7. 2801	93	8649	9. 6437
14	196	3. 7417	54	2916	7. 3485	94	8836	9. 6954
15	225	3. 8730	55	3025	7. 4162	95	9025	9. 7468
16	256	4. 0000	56	3136	7. 4833	96	9216	9. 7980
17	289	4. 1231	57	3249	7. 5498	97	9409	9. 8489
18	324	4. 2426	58	3364	7. 6158	98	9604	9. 8995
19	361	4. 3589	59	3481	7. 6811	99	9801	9. 9499
20	400	4. 4721	60	3600	7. 7460	100	10000	10. 0000
21	441	4. 5826	61	3721	7. 8102	101	10201	10. 0499
22	484	4. 6904	62	3844	7. 8740	102	10404	10. 0995
23	529	4. 7958	63	3969	7. 9373	103	10609	10. 1489
24	576	4. 8990	64	4096	8. 0000	104	10816	10. 1980
25	625	5. 0000	65	4225	8. 0623	105	11025	10. 2470
26	676	5. 0990	66	4356	8. 1240	106	11236	10. 2956
27	729	5. 1962	67	4489	8. 1854	107	11449	10. 3441
28	784	5. 2915	68	4624	8. 2462	108	11664	10. 3923
29	841	5. 3852	69	4761	8. 3066	109	11881	10. 4403
30	900	5. 4772	70	4900	8. 3666	110	12100	10. 4881
31	961	5. 5678	71	5041	8. 4261	111	12321	10. 5357
32	1024	5. 6569	72	5184	8. 4853	112	12544	10. 5830
33	1089	5. 7446	73	5329	8. 5440	113	12769	10. 6301
34	1156	5. 8310	74	5476	8. 6023	114	12996	10. 6771
35	1225	5. 9161	75	5625	8. 6603	115	13225	10. 7238
36	1296	6. 0000	76	5776	8. 7178	116	13456	10. 7703
37	1369	6. 0828	77	5929	8. 7750	117	13689	10. 8167
38	1444	6. 1644	78	6084	8. 8318	118	13924	10. 8628
39	1521	6. 2450	79	6241	8. 8882	119	14161	10. 9087
40	1600	6. 3246	80	6400	8. 9443	120	14400	10. 9545

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APPENDIX IV

GLOSSARY

Algebraic.—Pertaining to that branch of mathematics which uses letters and symbols.

Algebraic sum.—The addition of letters or numbers where some of them may represent negative quantities.

Alternating current.—Current that continually changes in magnitude and periodically reverses in direction.

Alternation.—One-half cycle of alternating current.

Alternator.—An a. c. generator.

Ammeter.—Current meter with a scale calibrated in amperes.

Ampere.—Unit of electric current equal to a coulomb per second.

Ampere hour.—Unit of electrical energy used in rating storage batteries; the product of amperes and hours.

Ampere turn.—Unit of magnetizing force; the product of amperes and turns.

Amplitude.—In connection with alternating current or any other periodic phenomena, the maximum value of the displacement from the zero position.

Angle.—The space between intersecting lines; the ratio between the arc and the radius of the arc.

Apparent power.—Product of volts and amperes in a. c. circuits where the current and voltage are out of phase.

Armature.—The rotating assembly of a d. c. motor or generator; also the iron part which completes the magnetic circuit in certain apparatus.

Atom.—One of the minute particles of which the universe is composed; a natural group of electrons and protons.

Average value.—Value obtained by adding a large number of values and dividing by the number added. For a half cycle of a sine curve the average is equal to .636 times the maximum.

Battery.—A device for converting chemical energy into electrical energy; two or more cells.

Capacitance.—Property of a circuit which opposes any change of voltage.

Capacitive reactance.—The effect of capacitance in opposing the flow of alternating or pulsating current.

Capacitor.—Same as condenser.

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Cell.—A combination of electrodes and electrolyte which converts chemical energy into electrical energy.

Characteristic.—A distinguishing trait, quality, or property.

Chemical.—Of or pertaining to the science of the composition of substances and of their transformations.

Circuit.—A closed path or mesh of closed paths usually including a source of e. m. f.

Circuit breaker.—A device for opening a circuit automatically in case of overload.

Collector rings.—Means of conveying current to or from rotating parts of a. c. machinery.

Commutation.—The process of converting alternating current which flows in the armature of d. c. generators to direct current.

Commutator.—The part of d. c. rotating machinery which makes electrical contact with the brushes and connects the armature conductors to the external circuit.

Commutator ripple.—The small pulsations which take place in the voltage and current of d. c. generators.

Condenser.—A device for inserting the property of capacitance in a circuit; two or more conductors separated by a dielectric.

Conductance.—Property of a circuit which determines its ability to allow current to flow; the reciprocal of resistance.

Contactor.—A device for closing and opening electrical circuits remotely; a magnetically operated switch.

Control panel.—An upright panel, open or closed, where switches, rheostats, meters, etc., are installed for controlling and protecting electrical machinery.

Coulomb.—Unit used for measuring quantity of electrical charge; equal to the charge of 6.28×10^{18} electrons.

Coupling.—Term used to represent the means by which energy is transferred from one circuit to another.

Current.—Gradual drift of free electrons along a conductor.

Cycle.—In periodic phenomena, one complete set of the reoccurring events.

Density.—Concentration of anything; quantity per unit volume or area.

Dielectric.—Material which will not conduct an electric current.

Dielectric constant.—Ratio of the capacitance of a condenser with a dielectric between the plates to the capacitance of the same condenser with a vacuum between the plates.

Direct current.—Current which is constant in magnitude and direction.

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Effective value.—The value of alternating voltage or current which has the same effect as the corresponding value of direct voltage or current; for a sine curve the effective value is .707 times the maximum value.

Electricity.—One of the fundamental quantities in nature consisting of elementary particles, electrons, and protons, which is manifested as a force of attraction or repulsion, and also in work that can be performed when electrons are caused to move; a material agency which when in motion exhibits magnetic, chemical, and thermal effects, and when at rest is accompanied by an interplay of forces between associated localities in which it is present.

Electrode.—The solid conductors of a cell or battery which are placed in contact with the liquid; conductor which makes electrical contact with a liquid or gas.

Electrolyte.—The liquid in a battery or other electrochemical device.

Electromagnet.—Temporary magnet which is constructed by winding a number of turns of insulated wire about an iron core.

Electromotive force.—Difference of electrical potential or pressure measured in volts.

Electron.—One of the ultimate subdivisions of matter having about $\frac{1}{1845}$ of the mass of a hydrogen atom (carrying a negative charge of electricity); one of the negative particles of an atom.

Energy.—The capacity for doing work.

Excitor.—Small generator for supplying direct current to the alternator's field windings.

Farad.—Unit of capacitance equal to the amount of capacitance present when 1 volt can store 1 coulomb of electricity.

Field of force.—Region in space filled with force which spreads out in all directions and will act through a vacuum.

Flux.—Magnetic field which is established in a magnetic circuit.

Force.—That which tends to change the state of rest or motion of matter.

Frequency.—In periodic phenomena the number of complete reoccurrences in unit time; in alternating current the number of cycles per second.

Fuse.—A circuit protecting device which makes use of a substance which has a low melting point.

Generator.—A device for converting mechanical energy into electrical energy.

Henry.—Unit of inductance; the inductance present which will cause 1 volt to be induced if the current changes at the rate of 1 ampere per second.

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Hydrometer.—Device for measuring the specific gravity of liquids.
Hypotenuse.—The side opposite the 90° angle of a right triangle.
Hysteresis.—A lagging or retardation of the effect when the forces acting upon a body are changed; encountered both in magnetic and dielectric phenomena.
Impedance.—The total opposition to the flow of alternating or pulsating current.
Inductance.—Property of a circuit which opposes a change in current.
Induction.—The act or process of producing voltage by the relative motion of a magnetic field and a conductor.
Inductive reactance.—The opposition to the flow of alternating or pulsating current due to the inductance of the circuit.
Instantaneous value.—When a value is continually varying with respect to time a value at any particular instant is known as the instantaneous value.
Insulator.—A medium which will not conduct electricity.
Joule.—Unit of energy or work equal to a watt second.
Leakage.—Term used to express current loss through imperfect insulators.
Kilowatt.—Unit of power equal to 1,000 watts.
Kilowatt hour.—Unit of electrical energy; equal to kilowatts multiplied by hours.
Line of force.—A path through space along which a field of force acts and shown by a line on a sketch.
Magnetic pole.—Region where the majority of magnetic lines of force leave or enter the magnet.
Magnetism.—The property of the molecules of certain substances, as iron, by virtue of which they may store energy in the form of a field of force and is due to the motion of the electrons in the atoms of the substance; a manifestation of energy due to the motion of a dielectric field of force.
Magnetomotive force.—The force which is necessary to establish flux in a magnetic circuit or to magnetize an unmagnetized specimen.
Matter.—Anything which has weight and occupies space.
Maximum value.—The greatest instantaneous value of an alternating voltage or current.
Megohm.—A large unit of resistance; equal to one million ohms.
Microfarad.—Practical unit of capacitance; one-millionth of a farad.
Milliampere.—Small unit of electric current; equal to one-thousandth of an ampere.
Molecule.—A small natural particle of matter usually composed of two or more atoms.

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Motor.—A device for converting electrical energy into mechanical energy.

Motor starter.—Device for protecting electric motors from excessive current while they are reaching full speed.

Mutual inductance.—Inductance associated with more than one circuit.

Network.—Special type of electrical circuit which cannot be classified in terms of series and parallel parts.

Ohm.—Fundamental unit of resistance.

Ohmmeter.—Device for measuring resistance by merely placing test prods across the resistor to be measured and reading the indication on a calibrated scale.

Peak value.—Same as maximum value.

Period.—The time required for the completion of one cycle.

Permanent magnet.—Piece of steel or alloy which has its molecules lined up such that a magnetic field exists without the application of a magnetizing force.

Permeability.—Reciprocal of reluctance; a measure of the ease with which flux can be established in the magnetic circuit; a ratio of the flux produced by a current-carrying coil with a core to that without a core.

Phase.—The portion of a whole period which has elapsed since the thing in question passed through its zero position in a positive direction.

Physical.—Of or pertaining to matter and material things involving no chemical changes.

Potential.—A characteristic of a point in an electric field or circuit indicated by the work necessary to bring a unit positive charge to it from infinity; the degree of electrification as referred to some standard as that of the earth.

Potential difference.—The arithmetical difference between two electrical potentials; same as electromotive force, electrical pressure, or voltage.

Power.—The rate of doing work or the rate of expending energy.

Power factor.—Ratio of true power to apparent power; equal to the cosine of the phase angle between the voltage and current.

Property.—A peculiar quality of a thing, substance, or phenomena.

Proton.—The positive particles of an atom.

Pulsating direct current.—Current which varies in magnitude but not in direction.

Rectifier.—Device for changing alternating current to pulsating direct current.

Relay.—Device for controlling electrical circuits from a remote position; a magnetic switch.

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Reluctance.—The opposition to magnetic flux.
Resistance.—The opposition to the flow of electric current.
Rheostat.—A variable resistance for limiting the current in a circuit.
Right triangle.—A triangle which has one 90° angle.
Rotor.—The rotating part of an a. c. induction motor.
Self-inductance.—Inductance associated with but one circuit.
Sensitivity.—The degree of responsiveness measured inversely; in connection with current meters it is the current required for full scale deflection; in connection with voltmeters it is the ohms per volt of scale on the meter.
Sine of an angle.—One of the trigonometric functions of an angle; in connection with a right triangle the ratio of the side opposite the angle to the hypotenuse.
Sine curve.—The graph obtained by plotting the sine of an angle against degrees.
Solenoid.—A tubular coil for the production of a magnetic field; electromagnet with a core which is free to move in and out.
Speed.—Time rate of motion measured by the distance moved in unit time; in rotating machinery it is the revolutions per minute or R. P. M.
Specific gravity.—The ratio of the mass of a body to the mass of an equal volume of water at 4° centigrade.
Stator.—The part of an a. c. generator or motor which has the stationary winding on it.
Switch.—A device for opening or closing an electrical circuit.
Synchronous.—Having the same period and phase; happening at the same time.
Temperature.—The condition of a body which determines the transfer of heat to or from other bodies; condition as to heat or cold; degree of heat or cold.
Thermocouple.—A device for directly converting heat energy into electrical energy.
Torque.—The effectiveness of a force to produce rotation about a center.
Transformer.—Device for raising or lowering a. c. voltage.
Triangle.—Closed figure bounded by three straight lines.
True power.—The actual power consumed by an a. c. circuit and equal to I^2R; expression used to distinguish from apparent power.
Volt.—Unit of potential, potential difference, e. m. f., or electrical pressure.
Voltage regulator.—Device used in connection with generators to keep the voltage constant as load or speed is changed.

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Voltmeter.—An instrument for measuring potential difference or electrical pressure.

Watt.—The unit of electrical power; equal to a joule per second.

Wattmeter.—An instrument for measuring electrical power.

Weight.—The force with which a body is attracted toward the center of the earth by the gravitational field of force.

Work.—The result of a force acting against opposition to produce motion, and is measured in terms of the product of the force and the distance it acts.

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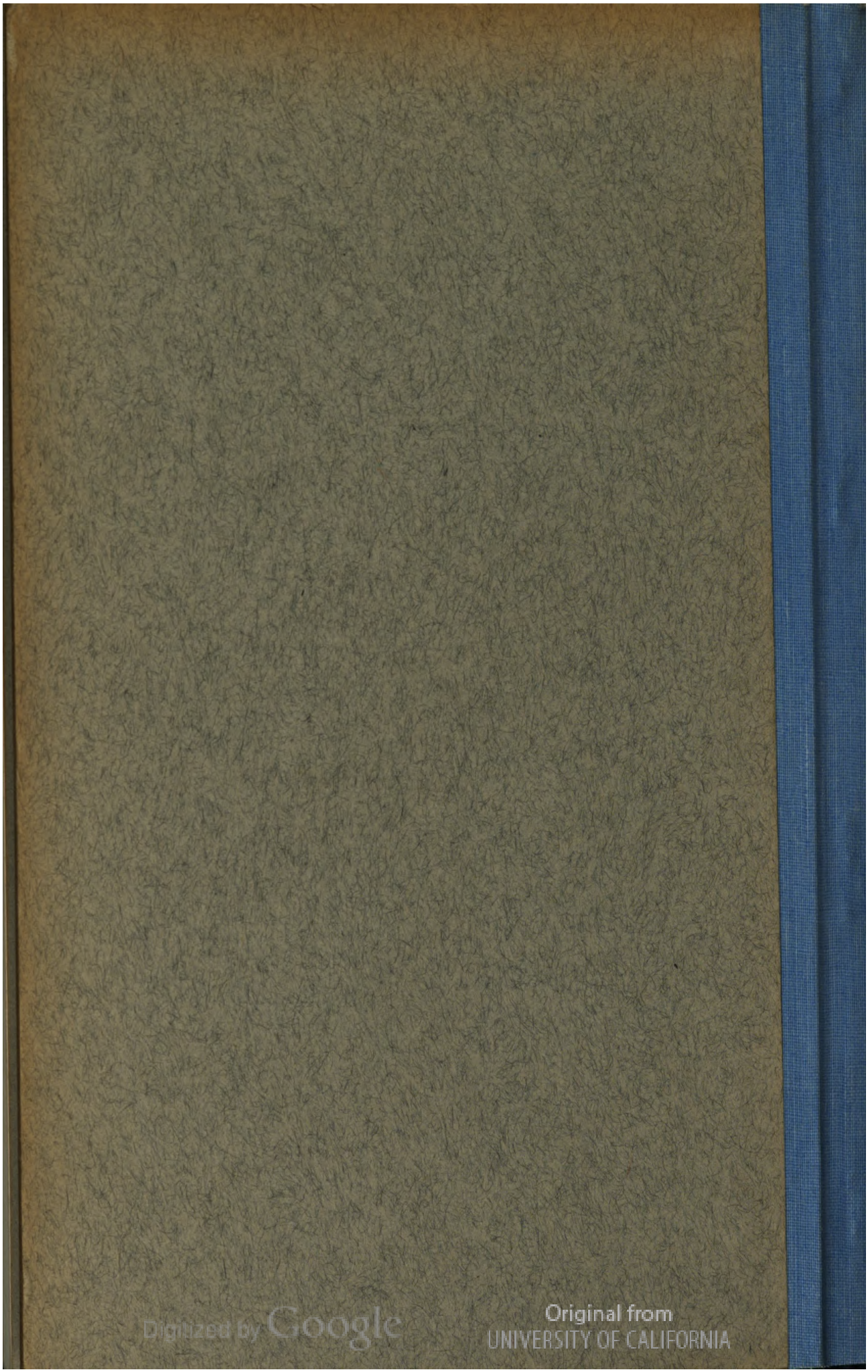
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