FOR OFFICIAL USE ONLY

ELEMENTARY ELECTRICITY

Training Pamphlet
No. 1

Signal Corps, U. S. Army
5-10-18

Gift of
H. L. Leupp

Elementary Electricity

Electricity and magnetism are the two things which form the basis of most signalling work in modern warfare. What they are is impossible to state, but there need not be so much concern with that as with what they do.

Magnetism is a property possessed by some metals whereby they attract or repel other pieces of metal. If small pieces of iron or steel are placed near a permanent steel magnet, they will be attracted, and when the force is great enough will jump to the magnet. This is what happens when the armature of a telegraph instrument jumps over against the pole of the magnet to produce the familiar click.

If, instead of testing this magnetism with a steel magnet and ordinary pieces of iron, two steel magnets are used, it is discovered at once that in one position the ends of the bars strongly attract each other, while if one of the bars is reversed, they repel each other, Fig. 1. This indicates that there is a difference between the magnetism at the two ends of a bar. Since the earth is magnetic toward the poles, it has been agreed that the end of the magnet which is attracted toward the north shall be called the "north pole" of that magnet, and that the opposite end shall be called the "south pole."

The law of magnetism is that unlike poles attract and like poles repel.

It should be noted that inasmuch as the north pole of the magnet is attracted toward the north pole of the earth, it is in reality a south magnetic pole. The magnetic pole of the earth is not exactly at the geographic pole. There are also magnetic variations due to the makeup of the earth which change with time. Consequently, a compass made of a small pivoted permanent magnet does not point directly north, Fig. 2, but has a slight deviation from this true north direction which is called the "magnetic deviation." To get the true north from a compass, this deviation, which varies for different points on the earth's surface, must be known.

Methods of Magnetizing

A bar of steel may be magnetized by bringing it near to another strong magnet, Fig. 3, by stroking it with another magnet, Fig. 4, or by bringing it under the magnetic influence that always surrounds an electric current, Fig. 5. Steel will retain most of this magnetism, and it is therefore called a "permanent magnet." A piece of soft iron becomes a magnet under the same influence, in fact, a much stronger magnet than a similar piece of steel, but when the inducing force is removed, all but a small residual magnetism is lost.

Theory of Magnetism

The supposition that seems to best explain the observed phenomena of magnetism, is that the metal is made up of small particulars called molecules, each of which is a small permanent magnet with north and south poles. As these are ordinarily all mixed up, unlike poles will tend to point towards each other inside the metal and there will be no total outside magnetic effect from the whole piece. Under the influence of magnetism, the molecules become oriented so that they all point in one direction magnetically, and their total effect is added. By cutting up a long permanent magnet, it is found that each piece becomes a complete magnet, this supporting the molecular theory. It is easier for the molecules to turn in a piece of soft iron than it is in steel, so that the effect is greater in iron. But in steel, once they are turned, they are more likely to remain that way. It should be remembered that permanent magnets must not be struck a sharp blow for this disturbs the magnetic balance and tends to assist the molecules to return to their former positions with a consequent loss of magnetism in the total piece. The positions of the molecules in a bar before and after the influence of magnetism are shown in Fig. 6.

The effect of magnetism passes through any substance. It cannot be insulated. However, it can all be made to pass within an iron or steel casing, as in this case, the surrounding iron forms a good conductor for the magnetic lines of force, which then tend to follow the path of least resistance. The lines of force can thus be controlled in a large measure.

A medium, called "ether," is assumed to be present in all matter and space. Magnetism is considered to be strains in this ether. These strains grade off in intensity outside the magnet from one pole to the other. Iron filings sprinkled on a paper over a permanent magnet take up positions in curved lines extending from one pole to the other, similar to that shown in Fig. 3. These lines represent the directions along which the ether strains change uniformly and are called the "magnetic lines of force."

Electricity

Electricity is assumed to consist of small particles called electrons. When these follow each other along a course, as they do most easily in a wire, the result is an electric current which is the all important thing in signalling. In order to have a flow of electric current, there must be more electrons in one portion of the circuit than in another. Such a condition may be brought about by the use of a battery or of a machine which generates electricity, called a dynamo or generator. There is an average concentration of these electrons all over the surface of the earth, which is considered to be the zero potential. These electrons have been found to have a negative charge. From the assumption scientists originally made, a body having more than the average earth concentration of these electrons is considered to have a negative electric potential. If it has less than the average concentration of electrons, it has a positive electric potential. The original assumption of the direction of current flow was made by scientists previous to the discovery of the electron theory for explaining the flow of current, and since then their assumption has been taken quite generally to be wrong. By this is meant, the direction of movement of the electrons is from negative to positive, while the direction of the electric current was assumed to be from positive to negative, Fig. 7. However, in elementary electricity, there is not so much concern with electrons as there is with the direction of flow and quantity of current.

Bodies electrically charged behave in some ways like the poles of magnets, that is, like charges repel and unlike charges attract. If two objects have unequal concentration of electrons, and they are connected together, the electrons will flow along the wire to balance up the concentration. The direction of this flow will be from the object having the greater concentration of electrons, or the negative electric potential, to the object having the lesser concentration of electrons, or the positive electric potential. The direction of current flow, according to the old assumption, is then just the opposite, from positive to negative.

If there is a steady flow of current in one direction, this is called a "direct current," Fig. 8. If the current flows first in one direction and then in the opposite direction, this is called an "alternating current," Fig. 9. If it always flows in one direction, but its value changes between the limits of a maximum and zero, it is then called a "pulsating current."

Primary Batteries

As stated above, in order to secure a flow of current, it is necessary to have a difference of potential existing in the circuit. One of the simplest ways of bringing this about is by means of a chemical cell. Such a cell transforms chemical energy into electrical energy, and is known as a "primary cell." There are a large number of possible combinations of metals and chemicals which can be used to make up an ordinary primary cell, some being more effective than others, and each having its respective advantages. In simplest form, the primary cell consists of two different metal plates suspended in an acid solution, called the "electrolyte." This acid has different effects upon the two plates, Fig. 10. For example, with copper and zinc as the two metals suspended in a dilute solution of sulphuric acid, the zinc is much more readily attacked by the acid than the copper. If these plates are connected together by means of a wire outside of the cell, a vigorous chemical action takes place, the zinc dissolving in the acid to form zinc sulphate and liberate hydrogen. The hydrogen liberated carries a negative charge of electricity which travels across the acid to the copper plate, there giving up its charge to the copper plate and passing off as gas. This causes a difference of potential on the two plates so that a current flows in the exterior circuit.

This difference of potential may also be explained by reverting to electrons. The reaction of the acid with the metal changes the physical shape very slightly, of course, in a unit of time, and in consequence of this eating away of the metal brings about a change in the density of the electrons on the metal. As this rate of change on the two metals is unequal, there is consequently a difference of potential set up between the two plates. The electric potential or voltage of a cell therefore does not depend upon the size of the cell but only on the elements used. However, the quantity of electricity which can be easily taken from a cell, and the speed with which it can be drawn off, do depend on the magnitude of the reaction taking place; that is, the larger the cell the greater the current supply available, Fig. 10.

The metals which may be used as the poles of a cell are listed below according to their relative potential when dipped into a solution acting as an electrolyte. Those near the top of the list are positive to those below. This list is known as the electro-chemical series.

Positive Terminal.—Carbon.
Platinum.
Silver.
Copper.
Lead.
Tin.
Iron.
Zinc—Negative Terminal.

The maximum electric pressure or voltage that can be obtained from any combination of these metals, is about three volts, whereas the current capacity is limited only by the size of the cell.

The ordinary dry cell consists of a zinc cylinder which serves as a container and acts as one plate or pole of the cell. This container is filled with a moist mixture which acts as the electrolyte. A central carbon cylinder or plate forms the positive pole. As cells are used, gases collect at the plates which tend to reduce the chemical action and lower the voltage and output of the cell. The cell is then said to be "polarized." This is lessened to a certain extent by the help of a chemical substance which acts to absorb this gas and is called a "depolarizing agent." But in spite of the depolarizer, a battery gradually becomes polarized and its usefulness dissipated. Such a battery may be renewed and further output obtained, in case of emergency, by heating it.

Storage Batteries

The secondary or storage cell, which also finds extensive use in Signal Corps work, is one which generates electricity

FIG.1

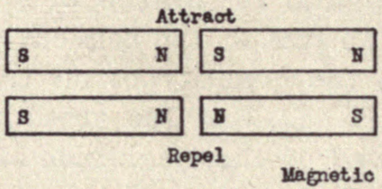
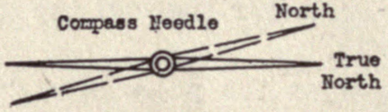


FIG.2



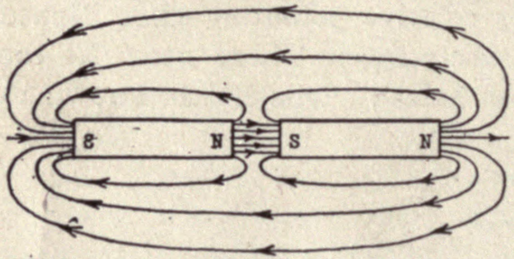


FIG.3 Magnetic Lines of Force

FIG.4

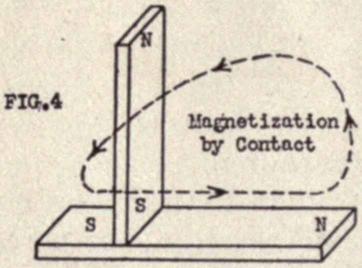


FIG. 5 Electrical Magnetization

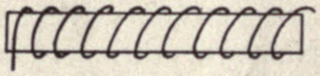
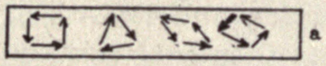


FIG. 6

Iron Bar,Demagnetized,



Iron Bar, Magnetized

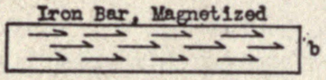


FIG. 7

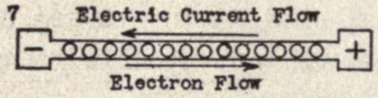
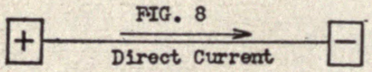


FIG. 8



Direct Current

FIG. 9

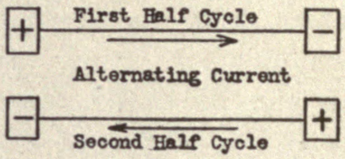
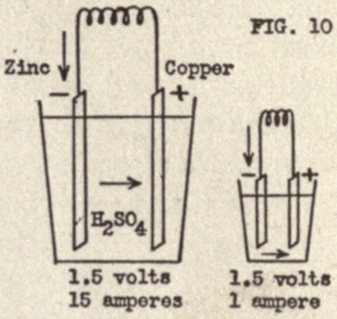
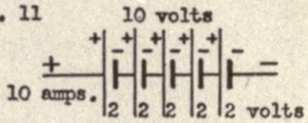


FIG. 10



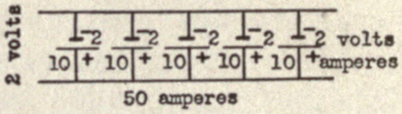
Batteries in Series

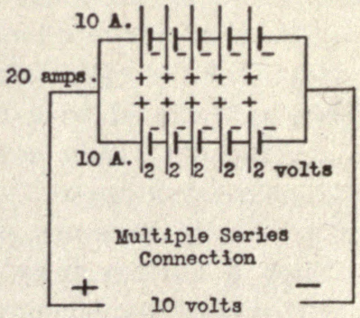
FIG. 11



Batteries in Parallel

FIG. 12





Multiple Series Connection

FIG. 13

by means of chemical reaction, just as in the primary cell. It differs from the primary cell, however, in that when the chemical action has gone on to such a point that the battery is exhausted, it may be restored to its former or charged condition by connecting it to some source of electricity for a period of time. In such a cell, the chemical reactions are reversible; that is, the two plates or poles of the cell are made up of such materials as may be chemically changed due to the passage of an electric current. And then upon using the cell as a source of electricity, this chemical reaction reverses itself to generate the electricity which has been stored through the previous chemical action.

The ordinary primary cell will respond to such a treatment only to a very slight degree. The elements which perform this reversible function most satisfactorily, are either lead plates coated with an active material of lead oxide and lead peroxide inserted in a dilute solution of sulphuric acid, or steel plates containing nickel and nickel hydrate and iron oxide inserted in an electrolyte of potassium hydroxide. The details of the chemical reactions taking place in both of these types of storage batteries, and full information as to care and charging, etc., are given in Radio Pamphlets No. 8 and No. 8-A, which are available when requested upon proper authority from the Land Division, Office of the Chief Signal Officer of the Army.

In both primary and secondary cell considerations, the "cell" is the individual generating element. Any group of these cells for producing a given power supply is called a "battery."

Battery Connections

The voltage of a single cell, either primary or secondary, is generally insufficient to do the work required. Batteries are therefore connected up in combinations to deliver the output and voltage desired. Cells are connected in series, Fig. 11, when it is desired to build up the voltage. This is done by connecting the positive terminal of one cell to the negative terminal of the next. If it is desired to obtain greater current through the exterior circuit, larger cells must be used, or what amounts to the same thing, the like plates of several cells must be connected together so that they all act together.

This gives the same voltage as one cell but increases the quantity of electricity available. This is called "multiple" or "parallel" connection, Fig. 12. When it is desired to increase both voltage and current, it is necessary to make a connection which is a combination of the series and multiple methods mentioned above, and called the "series-multiple" and "multiple-series" connections. Any combination of cells in this method of connection may be made; for instance, the cells may be connected as shown in Fig. 13 so that there will be two groups of five cells each in series, with the groups connected in parallel; or as shown in Fig. 14 so that there may be two groups of five cells each in parallel, with the groups connected in series, or any combination between these two limits.

Poorly made battery connections is one of the most common sources of trouble in the use of electrical instruments. At the same time, it is one of the most easy to avoid and to correct. In making connections, pincers should always be used to tighten down the nuts, and the surfaces should always be clean so that there will be a sure and firm contact. It is important that the pasteboard covers on dry cells should not be broken or removed, since if two of the zinc containers touch each other, a short circuit will result.

The direction of flow of an electric current may be determined by placing two terminals in a salt solution. The terminal at which the larger amount of gas is given off is the negative terminal, or where the current is flowing toward the cell. The values of current and voltage which are placed on the several illustrations showing different methods of battery connection, are those which obtain when the batteries used are lead plate storage batteries. If Edison storage batteries are used instead, the cell voltage averages 1.2 volts, and for dry batteries, it averages 1.5 volts. The output, of course, depends upon the construction of the cell.

Electrical Units

All substances will conduct electricity but there is a vast difference in the ease with which the electrons can pass through different substances. The opposition which the substance offers to the passage of the electrons, or electric current, is called its "resistance" and the unit of resistance is the "ohm." The "international ohm" is the resistance offered to the flow of an unvarying current by a column of mercury 106.3 centimeters high and weighing 14.4521 grams at a temperature of 0 deg. Centigrade. The converse of resistance, or the ease with which a substance conducts electricity, is called its "conductivity." A piece of copper wire 1/10 inch in diameter (No. 10 B. & S. gage) 1,000 feet long, has a resistance of 1 ohm. The resistances of various metals and other substances relative to the resistance of copper, which is taken as the standard, are given in the following table. It should be remembered that the lower the resistance the better the conductor.

Good Conductors.	
Silver	.925
Copper (annealed)	.975
Copper (standard)	1.00
Gold	1.38
Aluminum	1.61
Zinc	3.62
Platinum	5.65
Iron	5.70
Nickel	5.78
Tin	8.28
Lead	12.8
Antimony	22.8
Mercury	59.3
Bismuth	82.2

Fair Conductors.

Charcoal and Coke
Carbon
Plumbago
Acid Solutions
Sea Water
Salt Solutions
Metallic Ores
Living Vegetable
Moist Earth

Partial Conductors.

Water
The Body
Flame
Linen
Cotton
Dry Woods
Marble

Very Poor Conductors or Insulators.

Slate
Oils
Porcelain
Dry Leather, Paper
Wool
Silk
Sealing Wax
Sulphur
Resin
Gutta Percha
Shellac
Ebonite
Mica
Jet
Amber
Paraffine Wax
Glass (varies with quality)
Dry Air

To cause electricity to do any particular work, it is necessary to get a certain amount of it at the spot where the work is to be done. Electricity is not like water which can be stored in tanks at the spot where it is wanted. The effect of electricity comes from the rate at which it flows at the spot in question. This corresponds to gallons of water per minute. The electrical unit for rate of flow is the "ampere." The "international ampere" is that unvarying current which, when passed through a neutral solution of silver nitrate, will deposit silver at the rate of .001118 gram per second. (A convenient way of remembering this figure is that it is made up of one point, two naughts, three ones, and four twos—8.) To secure the desired rate of flow, electricity must be forced through the resistance between the point of supply and the point of use, and it must then also be forced through the apparatus. A pressure must therefore exist behind the electricity. This corresponds to the pressure shown by a steam gage and in electrical quantities is called the "voltage" or "electromotive force" (emf.). The unit of voltage is the "volt." For all practical purposes, the volt may be defined as that emf. which will cause one international ampere to flow through one international ohm.

These three units of resistance, current and voltage were so chosen that the pressure of one volt would force a current of one ampere through a resistance of one ohm. This relation continues, so that it requires twice as much voltage to force twice as much current through the same resistance, or that it takes twice as much voltage to force the same amount of current through twice the resistance. This relation is known as Ohm's law and may be expressed by the simple equation

$$I = \frac{E}{R},$$

where E is the voltage, I the current in amperes, and R the resistance in ohms. Knowing two of the quantities, it is always possible to find the third. The law is often expressed by inversions of the equation, as

$$E = IR, \text{ or } R = \frac{E}{I}.$$

The total resistance of separate resistances connected in series, is equal to the sum of the individual resistances. Hence in Fig 15,

$$R = r + r_1 + r_2 + r_3.$$

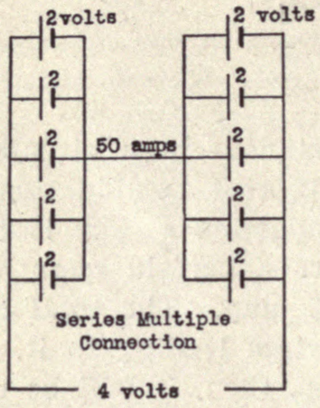
The total resistance of a circuit which has individual resistances connected in parallel is the sum of the conductivities of the various parts, or the sum of the reciprocals of the resistances. The greater the conductivity the less the resistance. Thus in Fig. 16 the total resistance may be found from the simple equation,

$$\frac{1}{R}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}.$$

With this knowledge of the resistances in a circuit, the need for connecting batteries in different combinations, as explained above, is more readily understood. For instance, suppose a specific apparatus requires a certain quantity of electricity to make it operate, say 5 amp. The total resistance of the apparatus and of the wires leading to it, is 10 ohms. In order to supply the 5 amp. then, it will be necessary to supply a voltage of 50 volts, since by Ohm's law, $E = RI$, hence $E = 10 \times 5 = 50$ volts. If the resistance of the exterior circuit connected to a cell is comparatively low, it is necessary to take into consideration the internal resistance of the battery in considering the constants of the circuit. The chemical action of the cells gives a certain amount of voltage. This voltage must force the current not only through the outside circuit but through the cell itself, and this latter becomes quite a large factor in the flow of current if the resistance of the exterior circuit is fairly low and a large current is desired. If the resistance of the exterior circuit is very high, the cell resistance may be neglected without material error in the computations.

Suppose that the battery in use in a circuit is made up of two small cells connected in series. Each cell gives a voltage of 1.5 volts normally and has an internal resistance of .3 ohm. The two cells in series give a battery voltage of 3 volts, and resistance of .6 ohm. Suppose, also, that the external circuit has a resistance of .2 ohm and that it is desired to force 6 amp. through it. If one of the above batteries is connected to the circuit, 3 volts are available for forcing the current through a total resistance of $.2 + .6 = .8$ ohm. From this, $I = \frac{E}{R} = \frac{3}{.8} = 3.75$ amperes. This is evidently not sufficient. Now place two of these batteries in series, Fig. 17. This will deliver 6 volts but will also double the internal resistance, making it 1.2 ohms, or a total of 1.4 ohms, including the external resistance. From this, $I = \frac{6}{1.4} = 4.28$ amperes. This

FIG. 14



Series Multiple Connection

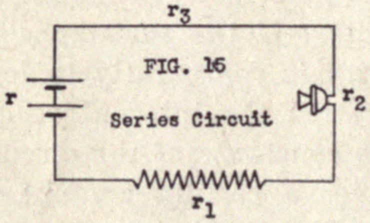


FIG. 15

Series Circuit

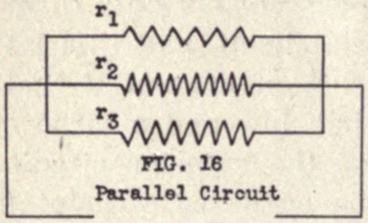


FIG. 16

Parallel Circuit

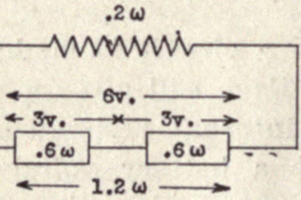


FIG. 17

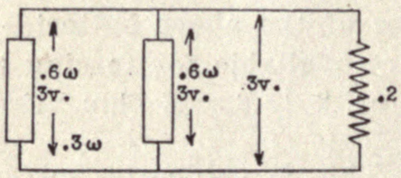
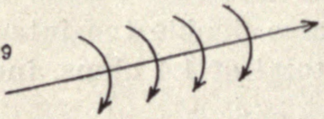


FIG. 18

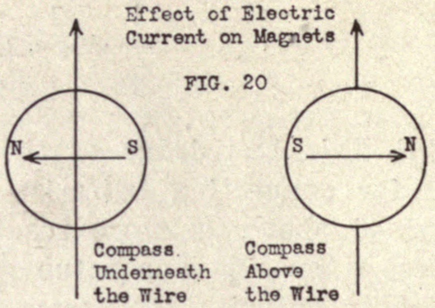
FIG. 19



Magnetic Field of Electric Current

Effect of Electric Current on Magnets

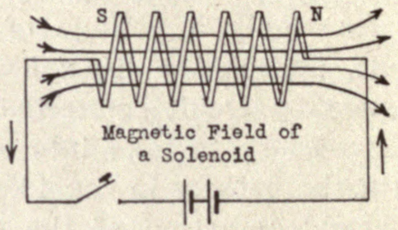
FIG. 20



Compass Underneath the Wire

Compass Above the Wire

FIG. 21



Magnetic Field of a Solenoid

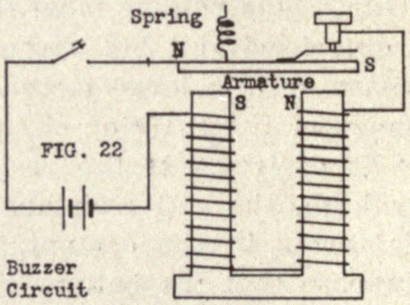


FIG. 22

Buzzer Circuit

Yoke

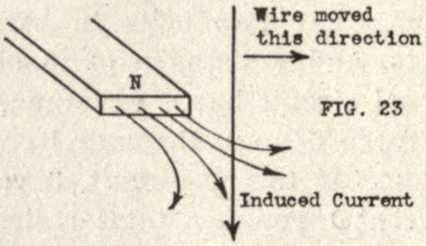
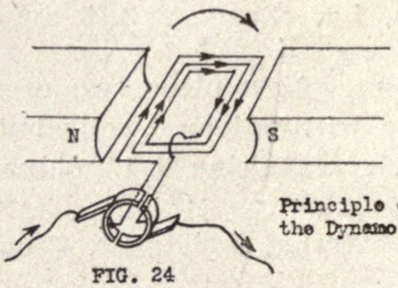


FIG. 23



Principle of the Dynamo

FIG. 24

is still not the amount desired, and it is seen that while the source of emf. has been doubled, the current which this will deliver through the exterior circuit has been increased only a small fraction—.5 amp.

If the two batteries are placed in parallel, Fig. 18, the voltage of only one will be available, 3 volts, but the internal resistance of the batteries will be decreased since two paths in parallel are provided for the current to pass through. This would give a total internal battery resistance of .3 ohm, according to the scheme shown above for finding a total resistance of several resistances in parallel, and this gives a total resistance in the circuit of $.3 + .2 = .5$ ohm. From this,

$$I = \frac{E}{R} = \frac{3}{.5} = 6 \text{ amp.}$$

A general rule which may be followed in such cases is to connect the batteries in series for use in circuits of high external resistance. With low external resistance, connect the batteries in parallel.

Ohm's law may be applied to any part of a circuit. That is, the voltage between any two points of a circuit is equal to the current flowing between those two points, multiplied by the resistance between those two points. Applying this formula to various portions of a circuit, shows where the maximum drop in potential occurs. For example, in an electric light circuit, the resistance of the light is far greater than that of the line, so that if 115 volts is supplied by the dynamo, practically all of that potential will be available at the lamp socket. The resistance of the wire to the lamp is very low in comparison to that of the lamp itself. When a large voltage is required for forcing a certain current through it, the power must be correspondingly large. The unit of power, in direct current circuits, is taken as the product of the voltage and amperage and is called the "watt." One watt of power is being applied when one ampere is flowing at one volt applied emf. This rule may be simply expressed by the equation

$$W = E I.$$

For example, a 6-amp. current flowing as the result of a 3-volt potential means a power input of 18 watts. In a lamp circuit, the current is ½ amp. at 110 volts, this representing

55 watts of power. A storage battery on charge at a pressure of 4 volts and a current rate of 15 amperes is taking 60 watts.

As a watt is a rather small unit, 1000 watts is the usual unit used and this is called a "kilowatt" (kw.). The electrical equivalent of the horse-power unit is 746 watts. One kilowatt is therefore almost exactly 1 1/3 hp.

The longer a certain number of watts of power is drawn from a source of supply, the greater the "energy" which is consumed. The unit of time used in this connection is the hour. A watt of power drawn for one hour is called a "watt-hour." It is not difficult to secure rather large currents for a very short time, but a substantial source of supply must be had to maintain a considerable current for a long time. The watt hour is the unit which expresses this requirement. As the watt-hour is a small unit, the usual unit used commercially is the kilowatt-hour (kw-hr.), 1000 watt-hours.

Electromagnetism

Whenever there is a flow of electric current, magnetic lines of force are found to circulate about it. The direction of these lines of force with respect to the direction of the current can easily be remembered by comparison with the "right hand rule." Consider the thumb to be the electrical conductor in which the current is flowing. Place the thumb in such a position that it will point in the direction the current is flowing in the wire. The direction in which the fingers curve around will then indicate the direction of the magnetic lines of force which are present about the wire. The lines of force are closed circles, however, and do not advance along the wire with the current, Fig. 19.

A magnetic compass placed over a wire carrying a current will be deflected to a position at right angles to the wire and pointing in one direction, and when placed underneath the wire, will be deflected in the opposite direction, Fig. 20. This serves as a further indication of the condition described by the right hand rule. The north pole of the compass will point in the direction of the lines of force. As the compass is moved around the wire, the needle will change its position, indicating the direction of the lines of force all the way around the wire.

The magnetism resulting from a single straight wire is of little value because it is so weak. But if the similar effect of a large number of wires is concentrated in a small space, the magnetic effect may be of considerable moment. This may be accomplished by coiling the wire so that many turns pass around the same space. This concentrates all the lines of force and when current is passing through the coil there exists what is commonly known as the "electromagnet." The effect may be made even more pronounced by placing a core of iron within the coil, since iron conducts magnetism about 1000 times more readily than air. By this construction, the lines of force created by each individual turn of wire, add up through the iron core of the coil to produce very strong magnetic poles at the ends of the core. A north magnetic pole is formed at one end of the core and a south pole at the opposite end. To determine at which end the north pole exists, the right hand rule may again be used. Place the thumb so that it will indicate the direction of current flow in any individual turn of wire of the coil, and at any position around the turn. The position of the fingers will then indicate the direction of the magnetic lines of force in the core, or will point towards the north pole of the magnet, Fig. 21.

For most purposes, it is better to construct the magnet so that the forces of both the north and south poles may be utilized to act on a small piece of iron called an armature, Fig. 22. This is done by placing an iron yoke across one end of two coils to form a closed magnetic path from the south pole of one coil around through the yoke to the north pole of the opposite coil. A bar of soft iron placed near the open end of the yoke is strongly affected by both poles, temporarily megnetizing the soft iron armature as indicated. Such an arrangement is essentially the construction used in the telegraph sounder, the ordinary door bell and many other electromagnetic devices.

Upon closing the circuit shown in Fig. 22, the armature would be drawn over against the poles and held there until the circuit was again broken. In a door bell, then, this would give simply one stroke of the bell. To make the bell ring continuously, it is necessary to insert a device for breaking the circuit each time the clapper is thrown against the bell. This is simply done by a spring contact on the armature through which the current energizing the coils passes. When the circuit is closed, the armature is drawn over toward the poles, opening the circuit at the spring contact. The coils then immediately release the armature which is drawn back by means of a coil spring, again closing the circuit. This again energizes the coil and draws over the magnet, breaking the circuit, etc., the cycle being completed with great rapidity.

Mechanical Generation of Electricity

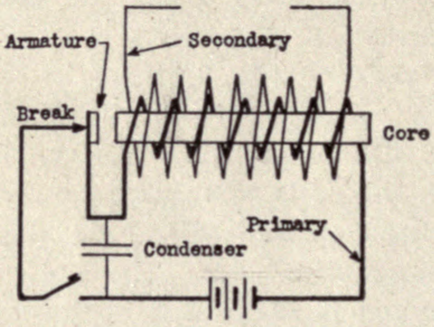
It has been shown that a current flowing through a wire produces a magnetic field around the wire. The converse of this is also true; that is, if a wire is moved across a magnetic field, Fig. 23, or if the wire remains stationary but a magnetic field moves across it, or any combination of motions take place such that the wire cuts magnetic lines of force, an emf. will be generated in the wire. Also if a magnetic field which passes through a coil of wire is suddenly created or destroyed, an emf. will be generated in that coil.

The dynamo is an example of a machine designed to generate electricity by this means of having a wire cut through a magnetic field, Fig. 24. Coils containing numerous turns of wire are wrapped around an armature which rotates within the magnetic field produced by other electromagnets, in such a way that the magnetic lines of force are cut by the coils on the armature. If the number of lines of force are increasing within a coil, the current will be forced in one direction. If the lines of force are decreasing in the coil, the current will be forced in the opposite direction. The general law covering this is called Lenz's law, and is, that the induced current is such that it opposes the motion producing it. Another statement of this law is, that the direction of any induced current is just the opposite of that current which would produce the magnetic lines of force cut by the wire.

If the current were lead off directly from the coils of a dynamo by means of brushes bearing on rings, to which the armature coils were connected, the current obtained would flow first in one direction and then in the other, depending on whether the number of lines of force cut was increasing or decreasing. In other words, an alternating current would be generated. To obtain direct current, a commutator is placed on the armature shaft instead of the rings and this is so made that just as the direction of current reverses in a coil, the connections to this coil are reversed so that the current obtained in the wires leading away from the commutator is always in the same direction, Fig. 24.

Generation of electricity by means of the dynamo is one form of electromagnetic induction. Another form of electromagnetic induction is that made use of in the ordinary induction coil, Fig. 25. In this case, the coils remain stationary, but in one coil the current is turned on and off. This alternately creates and destroys a magnetic field. The coil in which the circuit is made and broken is called the "primary" coil. Around this coil is wound another coil which is usually made up of a larger number of turns and is called the "secondary" coil. When the magnetic field is created in the primary coil due to a flow of current, the magnetic lines of force also pass through the secondary coil, and induce an emf. within it. When the circuit to the primary coil is closed, the magnetic field rapidly builds up to a certain maximum and then remains constant. During the time this magnetic field is changing in magnitude, an emf. is generated in the secondary coil with a magnitude which depends on the rate of change of the magnetic field due to the primary coil. Consequently when the field reaches its maximum strength, the rate of change is zero and no further current is produced in the secondary coil. But when the circuit to the primary is broken, there is again a change in the number of lines of force passing through the secondary coil as the magnetic lines of force through the primary decrease from a maximum to zero and another impulse of current is generated in the secondary during this change. The directions of flow of the current generated in the secondary coil during the building up of the magnetic field and during the falling off of the magnetic field are opposite. The large number of turns of wire on the secondary coil, as compared with the number on the primary coil, result in an electromotive force in the secondary coil which may be many times as great as that in the primary coil. By this means it is possible to step up the voltage and make it high enough to jump the high resistance of an air gap (20,000 volts are required to jump a gap of one inch between needle points). If the voltage is stepped up several times, the current in the secondary coil is correspondingly reduced in comparison to that in the primary, since the power

FIG. 25



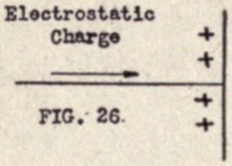


FIG. 26.

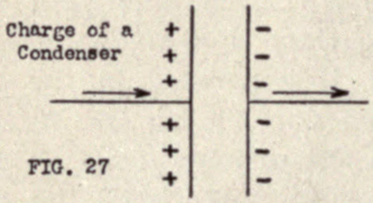


FIG. 27

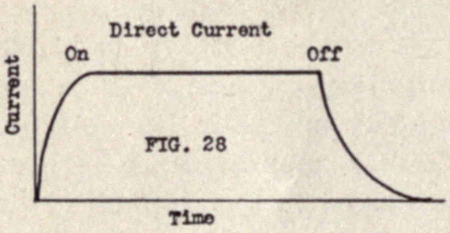


FIG. 28

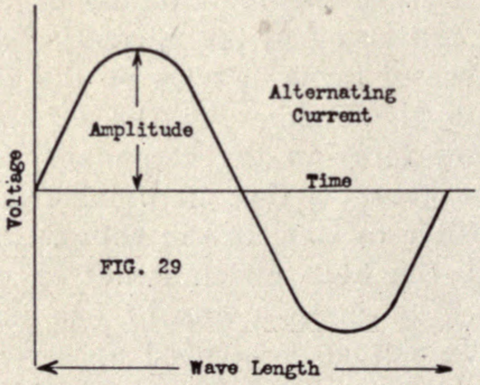


FIG. 29

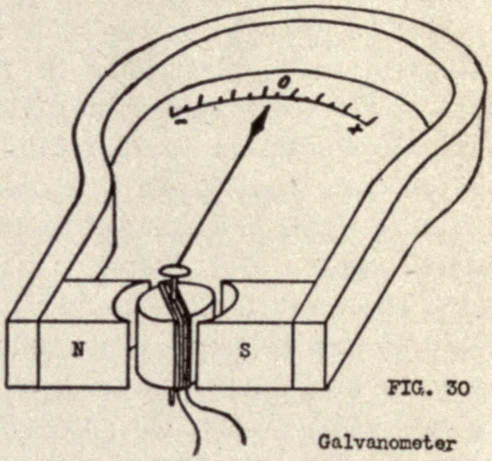


FIG. 30

Galvanometer

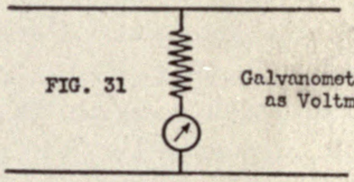


FIG. 31

Galvanometer Used as Voltmeter

Galvanometer Used as Ammeter

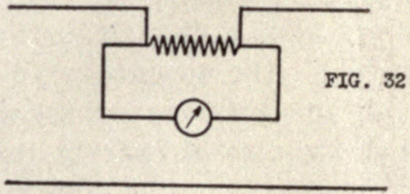


FIG. 32

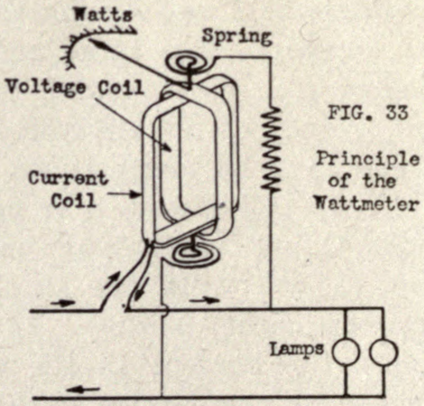


FIG. 33

Principle of the Wattmeter

output of the secondary can be no greater than the input to the primary, and since the product of the current and voltage is approximately the power. The high voltage obtained by this means is one of the essentials in radio telegraphy and telephony.

In order to secure a practically continuous supply of the high voltage current in the secondary circuit, it is necessary to make and break the circuit through the primary coil very rapidly. To do this, an armature and make and break contact system practically identical to that used in the ordinary door bell are used. This alternately makes and breaks the current through the primary coil and creates and destroys the magnetic field cutting the secondary coil and thereby induces the high voltage current, flowing first in one direction and then in the other.

The effect expressed in Lenz's law is always present whenever there is any change in the strength of a magnetic field. The force resulting from any change is always opposite to that producing it. This means that there is always a certain lag of the result behind the change producing that result. This effect is greatest in coils wound over iron cores in such a way that the lines of force produced by all the turns add up. The property of the coil which causes this lag is called the "reactance" of the coil.

Characteristics of Direct Currents

The whole science of electricity is that of using the various phenomena observed, in such combinations as produce the results desired. A direct current and alternating current have very different characteristics. A direct current requires a complete electric circuit in order to secure a flow in one direction. This means that none of the electrons will start to move without disturbing its next door neighbor, and thus will not move until all can follow along in one direction. The electrons are impelled by some chemical or magnetic force to start the motion. They communicate this impulse on ahead, and if the way is clear, that is, if the circuit is complete, the motion of the electrons continues and the direct current flows.

It has been found that electricity travels with a speed equal to that of light—300 million meters or 186,500 miles per second. This does not mean that the electrons travels along the wire at that rate, but that they communicate the impulse to move at that speed. The actual rate of motion of the electrons is dependent on the magnitude of current. If a wire 186,500 miles long were to be had, an electron at the far end of the wire would receive an impulse one second after the electron at the first end of the wire started to move. This speed seems incredible, as it really is, compared with the speed of which one is accustomed to think, but it is the normal speed of electricity. This simply means that everything in electrical circuits takes place in much shorter spaces of time than one is able to sense. But this time element involved in the flow of electric current, brief as it is, is a very real factor and various reactions in electricity are secured, particularly with respect to wireless work, only as the circuits are designed to take into account the time factor.

Resistance in a circuit hinders the motion of electrons. This property is a means of limiting the amount of motion, or in other words, the magnitude of the current. If there are coils inserted in the circuit, the self-induction between the turns will keep the emf. from building up as rapidly as it would in a circuit without the coils. This in some cases is a disadvantage, but it frequently is a handy means of preventing too sudden a flow of current through one part of a system.

If a large plate, Fig. 26, is connected at one end of a wire, and the other end of the wire connected to a source of electromotive force, there will be a distribution of electrons all over this plate. In order to bring about an increase in the concentration of electrons over the plate, the electrons coming over the wire must be made to spread out over this whole surface. This is brought about by increasing the voltage impressed on the plate through the wire. With a direct current connected to the plate in this manner, there results a short impulse of electricity as the electrons spread out over the plate to charge it to a potential corresponding to the voltage applied. When this voltage is withdrawn, this charge flows back along the line to equalize the distribution of electrons. If another plate is placed opposite the first, Fig. 27, an electric charge produced on one of these will induce an opposite charge on the other, due to the fact that the electric charge on the first acts in the same manner as the magnetic pole. Consequently, if the first plate charged has a positive potential, the opposite plate will be charged negatively so that the two plates will attract each other. Such a combinaion is ordinarily called a "condenser" and the amount of electricity represented by the concentration of electrons over the surfaces of the two plates is called the "capacitance" of the condenser. Its ability to hold electricity is a measure of its capacitance and it is expressed in units called "farads," or "microfarads" (mfd.), .000001 farad. The quantity of electricity that can be put in a condenser may be determined by the equation, $Q = E\,C$, where E is the voltage and C is the capacitance. Therefore the capacitance may be measured by

$$C = \frac{Q}{E}$$

Characteristics of Alternating Currents

Resistance opposes the progress of alternating current in the same manner that it does with direct current. With direct current, any inductance in the circuit interferes with the flow of current only when the circuit is made or broken or the strength of current changed, while with alternating current this effect goes on continuously with each change in the direction of the current. Consequently, inductance has a much greater effect on the current in the circuit and can actually prevent an alternating current from getting into a circuit at all. This is a very important factor, and one which is frequently very useful when it is necessary to use both direct and alternating current in the same circuit.

An alternating current will charge a condenser when the current flows in one direction and then when the current reverses this charge will flow back on the line, thereby helping the current flow in the other direction. The condenser then also charges in the opposite direction and discharges again in the first direction. Therefore, if a condenser is of the proper design, it will offer no hindrance to the flow of alternating current in a circuit including the condenser. Electrons never actually pass through the condenser, but their effect does, so that the "flow" of an alternating current may be considered to pass through a condenser. This difference in the reaction of the condenser upon a direct and upon an alternating current is also very useful in circuits in which both kinds of currents are employed.

It frequently facilitates explanation of electrical phenomena to represent current and voltage values by means of time curves. The voltage of a current changes with the time. Therefore, if distances are laid off on a line horizontally to represent time, then it is possible to represent voltage values during that time by the vertical distances above this horizontal line at the successive moments. For a direct current the voltage curve will show a steady rise to its maximum value and the curve will then be straight and parallel to the time axis until the current is cut off. Fig. 28 shows such a curve when there is an inductance coil in the circuit. With alternating current, however, the voltage is always changing from the maximum in the positive direction to the maximum in the negative direction. This makes a wave-like curve when plotted against time, Fig. 29. The "period" of an alternating current is the time required for one complete wave or cycle; that is, from the point of the horizontal axis that the curve is increasing in the positive direction, until it reaches the next point on the axis where it is again rising in the positive direction. Fig. 29 shows one complete wave. The "frequency" is the number of these cycles which occur in one second. The "amplitude" is the maximum value reached in either the positive or negative direction. The current values can be represented by a similar curve.

Measuring Instruments

All the common measuring instruments have as a basis the galvanometer, Fig. 30. This consists of a small coil of wire which swings in a permanent magnetic field. The needle is swung back to the zero position by a small hair spring. The coil is suspended so that it hangs in the zero position with its axis at right angles to the magnetic lines of force produced by the permanent magnet. When a small current enters the coil, it creates other lines of force at right angles to those of the permanent magnet, and in consequence the coil tends to turn to make all lines of force parallel. As the coil rotates about its axis, it increases the tension on the spring. Hence the amount of deflection is a measure of the intensity of current flowing through the coil.

When the galvanometer is used as a voltmeter, Fig. 31, a large resistance is placed in series with it so that at high voltages only a very small current will flow through the galvanometer coil. The scale is graduated to read in volts. The galvanometer itself is very sensitive so that care must be taken that only currents of the order of one-thousandth of an ampere will flow directly through the coil.

To use the galvanometer as an ammeter or current measuring instrument, Fig. 32, its terminals are placed across a low resistance shunt which is included in the main circuit. The galvanometer then measures the I R drop (E = I R) across the shunt. Since R is a constant for the particular shunt used, the galvanometer's deflection will be proportional to the current passing through the resistance.

To measure the power being delivered by any source of electromotive force, it is necessary to measure both the voltage and amperage. In this case, instead of having permanent magnets to create a field, a stationary coil is connected across the shunt which is connected in series with the circuit. The strength of the magnetic field produced in this coil will then vary with the amount of current flowing in the circuit. Another coil is then placed as with the galvanometer so that any magnetic lines of force produced by it will tend to turn the coil so that these lines will be parallel with those produced by the current coil. This voltage coil is connected through a high resistance across the line. Consequently the resulting deflection is due to the combined effect of both the current and the voltage existing in the circuit. The instrument is so designed that the deflection is proportional to the product of the two, or in other words, so that it will read directly in watts. Such an instrument is called a "wattmeter," Fig. 33.