Electricity

Air Washington Electronics ~ Direct Current Theory

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Matter, Energy, and Electricity

If there are roots to western science, they no doubt lie under the rubble that was once ancient Greece. With the exception of the Greeks, ancient people had little interest in the structure of materials. They accepted a solid as being just that: a continuous, uninterrupted substance. One Greek school of thought believed that if a piece of matter, such as copper, were subdivided, it could be done indefinitely and still only that material would be found. Others reasoned that there must be a limit to the number of subdivisions that could be made and have the material retain its original characteristics. They held fast to the idea that there must be a basic particle upon which all substances are built. Recent experiments have revealed that there are, indeed, several basic particles, or building blocks within all substances.

The following paragraphs explain how substances are classified as elements and compounds, and are made up of molecules and atoms. This, then, will be a learning experience about protons, electrons, valence, energy levels, and the physics of electricity.

MATTER

Matter is defined as anything that occupies space and has weight; that is, the weight and dimensions of matter can be measured. Examples of matter are air, water, automobiles, clothing, and even our own bodies. Thus, we can say that matter may be found in any one of three states: SOLID, LIQUID, and GASEOUS.

Elements and Compounds

An ELEMENT is a substance that cannot be reduced to a simpler substance by chemical means. Examples of elements with which you are in everyday contact are iron, gold, silver, copper, and oxygen. There are over 100 known elements. All the different substances we know about are composed of one or more of these elements.

When two or more elements are chemically combined, the resulting substance is called a COMPOUND. A compound is a chemical combination of elements that can be separated by chemical but not by physical means. Examples of common compounds are water, which consists of hydrogen and oxygen, and table salt, which consists of sodium and chlorine. A MIXTURE, on the other hand, is a combination of elements and compounds, not chemically combined, that can be separated by physical means. Examples of mixtures are air, which is made up of nitrogen, oxygen, carbon dioxide, and small amounts of several rare gases, and seawater, which consists chiefly of salt and water.

Molecules

A MOLECULE is a chemical combination of two or more atoms, (atoms are described in the next paragraph). In a compound, the molecule is the smallest particle that has all the characteristics of the compound.

Consider water, for example. Water is matter, since it occupies space and has weight. Depending on the temperature, it may exist as a liquid (water), a solid (ice), or a gas (steam). Regardless of the temperature, it will still have the same composition. If we start with a quantity of water, divide this and pour out one half, and continue this process a sufficient number of times, we will eventually end up with a quantity of water which cannot be further divided without ceasing to be water. This quantity is called a molecule of water. If this molecule of water divided, instead of two parts of water, there will be one part of oxygen and two parts of hydrogen (H_2O).

Atoms

Molecules are made up of smaller particles called ATOMS. An atom is the smallest particle of an element that retains the characteristics of that element. The atoms of one element, however, differ from the atoms of all other elements. Since there are over 100 known elements, there must be over 100 different atoms, or a different atom for each element. Just as thousands of words can be made by combining the proper letters of the alphabet, so thousands of different materials can be made by chemically combining the proper atoms.

Any particle that is a chemical combination of two or more atoms is called a molecule. The oxygen molecule consists of two atoms of oxygen, and the hydrogen molecule consists of two atoms of hydrogen. Sugar, on the other hand, is a compound composed of atoms of carbon, hydrogen, and oxygen. These atoms are combined into sugar molecules. Since the sugar molecules can be broken down by chemical means into smaller and simpler units, we cannot have sugar atoms.

The atoms of each element are made up of electrons, protons, and, in most cases, neutrons, which are collectively called subatomic particles. Furthermore, the electrons, protons, and neutrons of one element are identical to those of any other element. The reason that there are different kinds of elements is that the number and the arrangement of electrons and protons within the atom are different for the different elements

The electron is considered a small negative charge of electricity. The proton has a positive charge of electricity equal and opposite to the charge of the electron. Scientists have measured the mass and size of the electron and proton, and they know how much charge each possesses. The electron and proton each have the same quantity of charge, although the mass of the proton is approximately 1837 times that of the electron. In some atoms, there exists a neutral particle called a neutron. The neutron has a mass approximately equal to that of a proton, but it has no electrical charge. According to a popular theory, the electrons, protons, and neutrons of the atoms are thought to be arranged in a manner similar to a miniature solar system. The protons and neutrons form a heavy nucleus with a positive charge, around which the very light electrons revolve.

Figure 1 shows one hydrogen and one helium atom. Each has a relatively simple structure. The hydrogen atom has only one proton in the nucleus with one electron rotating about it. The helium atom is a little more complex. It has a nucleus made up of two protons and two neutrons, with two electrons rotating about the nucleus. Elements are classified numerically according to the complexity of their atoms. The atomic number of an atom is determined by the number of protons in its nucleus.

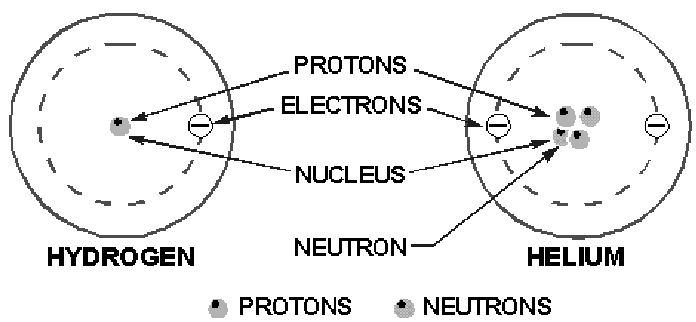

Figure 1 —Structures of simple atoms.

In a neutral state, an atom contains an equal number of protons and electrons. Therefore, an atom of hydrogen—, which contains one proton and one electron—has an atomic number of 1; and helium, with two protons and two electrons, has an atomic number of 2. The complexity of atomic structure increases with the number of protons and electrons.

Energy Levels

Since an electron in an atom has both mass and motion, it contains two types of energy. By virtue of its motion, the electron contains KINETIC ENERGY. Due to its position, it also contains POTENTIAL ENERGY. The total energy contained by an electron (kinetic plus potential) is the factor that determines the radius of the electron orbit. In order for an electron to remain in this orbit, it must neither GAIN nor LOSE energy. It is well known that light is a form of energy, but the physical form in which this energy exists is not known.

One accepted theory proposes the existence of light as tiny packets of energy called PHOTONS. Photons can contain various quantities of energy. The amount depends upon the color of the light involved. Should a photon of sufficient energy collide with an orbital electron, the electron will absorb the photon's energy, as shown in figure 2. The electron, which now has a greater than normal amount of energy, will jump to a new orbit farther from the nucleus. The first new orbit to which the electron can jump has a radius four times as large as the radius of the original orbit. Had the electron received a greater amount of energy, the next possible orbit to which it could jump would have a radius nine times the original. Thus, each orbit may be considered to represent one of a large number of energy levels that the electron may attain. It must be emphasized that the electron cannot jump to just any orbit. The electron will remain in its lowest orbit until a sufficient amount of energy is available, at which time the electron will accept the energy and jump to one of a series of permissible orbits. An electron cannot exist in the space between energy levels. This indicates that the electron will not accept a photon of energy unless it contains enough energy to elevate itself to one of the higher energy levels. Heat energy and collisions with other particles can also cause the electron to jump orbits.

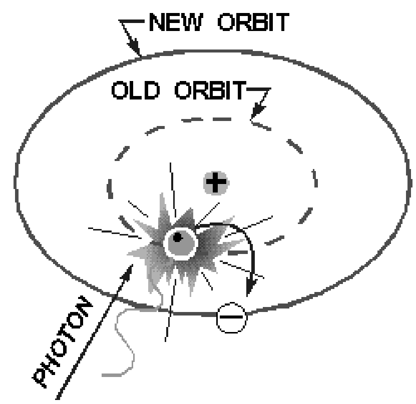

Figure 2 —Excitation by a photon.

Once the electron has been elevated to an energy level higher than the lowest possible energy level, the atom is said to be in an excited state. The electron will not remain in this excited condition for more than a fraction of a second before it will radiate the excess energy and return to a lower energy orbit. To illustrate this principle, assume that a normal electron has just received a photon of energy sufficient to raise it from the first to the third energy level. In a short period, the electron may jump back to the first level emitting a new photon identical to the one it received.

A second alternative would be for the electron to return to the lower level in two jumps from the third to the second, and then from the second to the first. In this case, the electron would emit two photons, one for each jump. Each of these photons would have less energy than the original photon that excited the electron.

This principle is used in fluorescent lights where ultraviolet light photons, which are not visible to the human eye, bombard a phosphor coating on the inside of a glass tube. The phosphor electrons, in returning to their normal orbits, emit photons of light that are visible. By using the proper chemicals for the phosphor coating, any color of light may be obtained, including white. This same principle is also used in lighting up the screen of a television picture tube.

The basic principles just developed apply equally well to the atoms of more complex elements. In atoms containing two or more electrons, the electrons interact with each other and the exact path of any one electron is very difficult to predict. However, each electron lies in a specific energy band and the orbits will be considered as an average of the electron's position.

Shells and Subshells

The difference between the atoms, insofar as their chemical activity and stability are concerned, is dependent upon the number and position of the electrons included within the atom. How are these electrons positioned within the atom? In general, the electrons reside in groups of orbits called shells. These shells are elliptically shaped and are assumed located at fixed intervals. Thus, the shells are arranged in steps that correspond to fixed energy levels. The shells and the number of electrons required to fill them, may be predicted by the employment of Pauli's exclusion principle. Simply stated, this principle specifies that each shell will contain a maximum of n*o* electrons, where *n* corresponds to the shell number starting with the one closest to the nucleus. By this principle, the second shell, for example, would contain 2(2)2 or 8 electrons when full.

In addition to being numbered, the shells are also given letter designations, as pictured in figure 3. Starting with the shell closest to the nucleus and progressing outward, the shells are labeled K, L, M, N, O, P, and Q, respectively. The shells are considered to be full, or complete, when they contain the following quantities of electrons: two in the K shell, eight in the L shell, 18 in the M shell, and so on, in accordance with the exclusion principle. Each of these shells is a major shell and can be divided into subshells, of which there are four, labeled *s*, *p*, *d*, and *f*. Like the major shells, the subshells are also limited as to the number of electrons that they can contain. Thus, the *s* subshell is complete when it contains two electrons, the *p* subshell when it contains 10, and the *f* subshell when it contains 14 electrons.

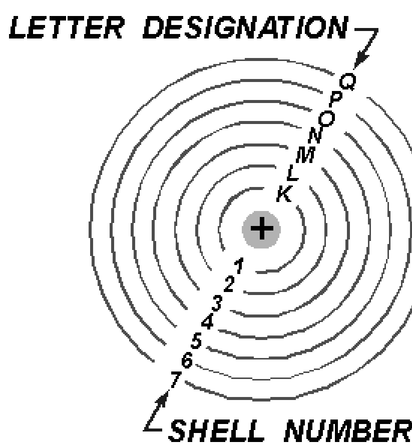

Figure 3—Shell designation.

Inasmuch as the K shell can contain no more than two electrons, it must have only one subshell, the *s* subshell. The M shell is composed of three subshells: *s*, *p*, and *d*. If the electrons in the *s*, *p*, and *d* subshells are added, their total is found to be 18, the exact number required to fill the M shell. Notice the electron configuration for copper illustrated in figure 4. The copper atom contains 29 electrons, which completely fill the first three shells and subshells, leaving one electron in the *s* subshell of the N shell.

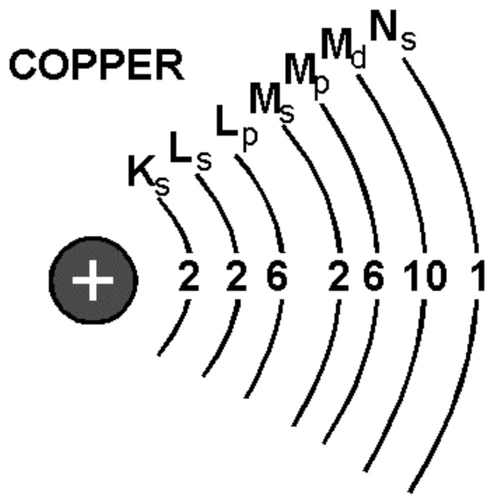

Figure 4—Copper atom.

Valence

The number of electrons in the outermost shell determines the valence of an atom. For this reason, the outer shell of an atom is called the VALENCE SHELL; and the electrons contained in this shell are called VALENCE ELECTRONS. The valence of an atom determines its ability to gain or lose an electron, which in turn determines the chemical and electrical properties of the atom. An atom that is lacking only one or two electrons from its outer shell will easily gain electrons to complete its shell, but a large amount of energy is required to free any of its electrons. An atom having a relatively small number of electrons in its outer shell in comparison to the number of electrons required to fill the shell will easily lose these valence electrons. The valence shell always refers to the outermost shell.

Ionization

When the atom loses electrons or gains electrons in this process of electron exchange, it is said to be IONIZED. For ionization to take place there must be a transfer of energy which results in a change in the internal energy of the atom. An atom having more than its normal amount of electrons acquires a negative charge, and is called a NEGATIVE ION. The atom that gives up some of its normal electrons is left with less negative charges than positive charges and is called a POSITIVE ION. Thus, ionization is the process by which an atom loses or gains electrons.

Conductors, Semiconductors, and Insulators

In this study of electricity and electronics, the association of matter and electricity is important. Since every electronic device is constructed of parts made from ordinary matter, the effects of electricity on matter must be well understood. As a means of accomplishing this, all elements of which matter is made may be placed into one of three categories: CONDUCTORS, SEMICONDUCTORS, and INSULATORS, depending on their ability to conduct an electric current. CONDUCTORS are elements that conduct electricity readily; INSULATORS have an extremely high resistance to the flow of electricity. All matter between these two extremes may be called SEMICONDUCTORS.

The electron theory states that all matter is composed of atoms and the atoms are composed of smaller particles called protons, electrons, and neutrons. The electrons orbit the nucleus, which contains the protons and neutrons. It is the valence electrons that we are most concerned with in electricity. These electrons are easiest to break loose from their parent atom. Normally, conductors have three or less valence electrons; insulators have five or more valence electrons; and semiconductors usually have four valence electrons.

The electrical conductivity of matter is dependent upon the atomic structure of the material from which the conductor is made. In any solid material, such as copper, the atoms that make up the molecular structure are bound firmly together. At room temperature, copper will contain a considerable amount of heat energy. Since heat energy is one method of removing electrons from their orbits, copper will contain many free electrons that can move from atom to atom. When not under the influence of an external force, these electrons move in a haphazard manner within the conductor. This movement is equal in all directions so that electrons are not lost or gained by any part of the conductor. When controlled by an external force, the electrons move generally in the same direction. The effect of this movement is felt almost instantly from one end of the conductor to the other. This electron movement is called an ELECTRIC CURRENT.

Some metals are better conductors of electricity than others are. Silver, copper, gold, and aluminum are materials with many free electrons and make good conductors. Silver is the best conductor, followed by copper, gold, and aluminum. Copper is used more often than silver because of cost. Aluminum is used where weight is a major consideration, such as in high-tension power lines, with long spans between supports. Gold is used where oxidation or corrosion is a consideration and a good conductivity is required.

The ability of a conductor to handle current also depends upon its physical dimensions. Conductors are usually found in the form of wire, but may be in the form of bars, tubes, or sheets.

Nonconductors have few free electrons. These materials are called INSULATORS. Some examples of these materials are rubber, plastic, enamel, glass, dry wood, and mica. Just as there is no perfect conductor, neither is there a perfect insulator.

Some materials are neither good conductors nor good insulators, since their electrical characteristics fall between those of conductors and insulators. These in-between materials are classified as SEMICONDUCTORS. Germanium and silicon are two common semiconductors used in solid-state devices.

Electrostatics

Electrostatics (electricity at rest) is a subject with which most persons entering the field of electricity and electronics are somewhat familiar. For example, the way a person's hair stands on end after vigorous rubbing is an effect of electrostatics. While pursuing the study of electrostatics, you will gain a better understanding of this common occurrence. Of even greater significance, the study of electrostatics will provide you with the opportunity to gain important background knowledge and to develop concepts that are essential to the understanding of electricity and electronics.

Interest in the subject of static electricity can be traced back to the Greeks. Thales of Miletus, a Greek philosopher and mathematician, discovered that when an amber rod is rubbed with fur, the rod has the amazing characteristic of attracting some very light objects such as bits of paper and shavings of wood.

About 1600, William Gilbert, an English scientist, made a study of other substances that had been found to possess qualities of attraction similar to amber. Among these were glass, when rubbed with silk, and ebonite, when rubbed with fur. Gilbert classified all the substances that possessed properties similar to those of amber as electrics, a word of Greek origin meaning amber. Because of Gilbert's work with electrics, a substance such as amber or glass when given a vigorous rubbing was recognized as being ELECTRIFIED, or CHARGED with electricity.

In the year 1733, Charles Dufay, a French scientist, made an important discovery about electrification. He found that when a glass was rubbed with fur, both the glass rod <u>and</u> the fur became electrified. This realization came when he systematically placed the glass rod and the fur near other electrified substances and found that certain substances, which were attracted to the glass rod, were repelled by the fur, and vice versa. From experiments such as this, he concluded that there must be two exactly opposite kinds of electricity.

Benjamin Franklin, American diplomat, inventor, and philosopher, is credited with first using the terms POSITIVE and NEGATIVE to describe the two opposite kinds of electricity. The charge produced on a glass rod when it is rubbed with silk, Franklin labeled positive. He attached the term negative to the charge produced on the silk. Those bodies that were not electrified or charged, he called NEUTRAL.

Static Electricity

In a natural or neutral state, each atom in a body of matter will have the proper number of electrons in orbit around it. Consequently, the whole body of matter composed of the neutral atoms will also be electrically neutral. In this state, it is said to have a "zero charge." Electrons will neither leave nor enter the neutrally charged body should it encounter other neutral bodies. If, however, any number of electrons is removed from the atoms of a body of matter, there will remain more protons than electrons and the whole body of matter will become ELECTRICALLY POSITIVE. Should the positively charged body encounter another body having a normal charge, or having a NEGATIVE (too many electrons) charge, an electric current will flow between them. Electrons will leave the more negative body and enter the positive body. This electron flow will continue until both bodies have equal charges. When two bodies of matter have unequal charges and are near one another, an electric force is exerted between them because of their unequal charges. However, since they are not in contact, their charges cannot equalize. The existence of such an electric force, where current cannot flow, is referred to as static electricity. ("Static" in this instance means, "not moving.") It is also referred to as an electrostatic force.

One of the easiest ways to create a static charge is by friction. When two pieces of matter are rubbed together, electrons can be "wiped off" one material onto the other. If the materials used are good conductors, it is quite difficult to obtain a detectable charge on either, since equalizing currents can flow easily between the conducting materials. These currents equalize the charges almost as fast as they are created. A static charge is more easily created between nonconducting materials. When a hard rubber rod is rubbed with fur, the rod will accumulate electrons given up by the fur, as shown in figure 5. Since both materials are poor conductors, very little equalizing current can flow, and an electrostatic charge builds up. When the charge becomes great enough, current will flow regardless of the poor conductivity of the materials. These currents will cause visible sparks and produce a crackling sound.

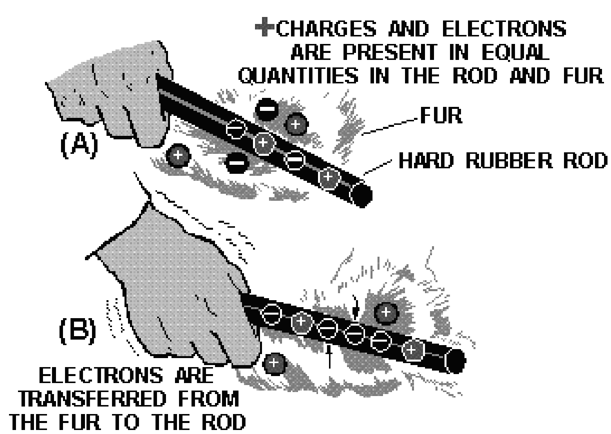

Figure 5—Producing static electricity by friction.

Nature of Charges

When in a natural or neutral state, an atom has an equal number of electrons and protons. Because of this balance, the net negative charge of the electrons in orbit is exactly balanced by the net positive charge of the protons in the nucleus, making the atom electrically neutral.

An atom becomes a positive ion whenever it loses an electron, and has an overall positive charge. Conversely, whenever an atom acquires an extra electron, it becomes a negative ion and has a negative charge.

Due to normal molecular activity, there are always ions present in any material. If the number of positive ions and negative ions is equal, the material is electrically neutral. When the number of positive ions exceeds the number of negative ions, the material is positively charged. The material is negatively charged whenever the negative ions outnumber the positive ions.

Since ions are actually atoms without their normal number of electrons, it is the excess or the lack of electrons in a substance that determines its charge. In most solids, the transfer of charges is by movement of electrons rather than ions. The transfer of charges by ions will become more significant when we consider electrical activity in liquids and gases. At this time, we will discuss electrical behavior in terms of electron movement.

Charged Bodies

One of the fundamental laws of electricity is that LIKE CHARGES REPEL EACH OTHER and UNLIKE CHARGES ATTRACT EACH OTHER. A positive charge and negative charge, being unlike, tend to move toward each other. In the atom, the negative electrons are drawn toward the positive protons in the nucleus. This attractive force is balanced by the electron’s centrifugal force caused by its rotation about the nucleus. As a result, the electrons remain in orbit and are not drawn into the nucleus. Electrons repel each other because of their like negative charges, and protons repel each other because of their like positive charges.

The law of charged bodies may be demonstrated by a simple experiment. Two pith (paper pulp) balls are suspended near one another by threads, as shown in figure 6.

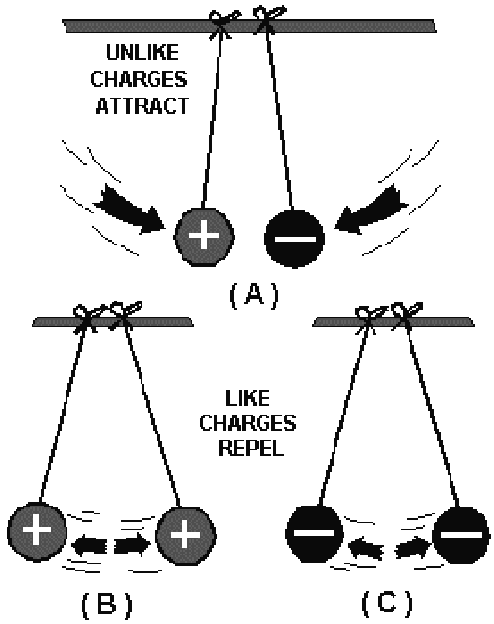

Figure 6—Reaction between charged bodies.

If a hard rubber rod is rubbed with fur to give it a negative charge and is then held against the right- hand ball in part (A), the rod will give off a negative charge to the ball. The right-hand ball will have a negative charge with respect to the left-hand ball. When released, the two balls will be drawn together, as shown in figure 6(A). They will touch and remain in contact until the left-hand ball gains a portion of the negative charge of the right-hand ball, at which time they will swing apart as shown in figure 6(C). If a positive or a negative charge is placed on both balls (fig. 6(B)), the balls will repel each other.

Coulomb's Law of Charges

The relationship between attracting and repelling charged bodies was first discovered and written about by a French scientist named Charles A. Coulomb. Coulomb's Law states that CHARGED BODIES ATTRACT OR REPEL EACH OTHER WITH A FORCE THAT IS DIRECTLY PROPORTIONAL TO THE PRODUCT OF THEIR INDIVIDUAL CHARGES, AND IS INVERSELY PROPORTIONAL TO THE SQUARE OF THE DISTANCE BETWEEN THEM.

The amount of attracting or repelling force which acts between two electrically charged bodies in free space depends on two things—(1) their charges and (2) the distance between them.

Electric Fields

The space between and around charged bodies in which their influence is felt is called an ELECTRIC FIELD OF FORCE. It can exist in air, glass, paper, or a vacuum. ELECTROSTATIC FIELDS and DIELECTRIC FIELDS are other names used to refer to this region of force.

Fields of force spread out in the space surrounding their point of origin and, in general, DIMINISH IN PROPORTION TO THE SQUARE OF THE DISTANCE FROM THEIR SOURCE.

The field about a charged body is generally represented by lines that are referred to as ELECTROSTATIC LINES OF FORCE. These lines are imaginary and are used merely to represent the direction and strength of the field. To avoid confusion, the lines of force exerted by a positive charge are always shown leaving the charge, and for a negative charge they are shown entering. Figure 7 illustrates the use of lines to represent the field about charged bodies.

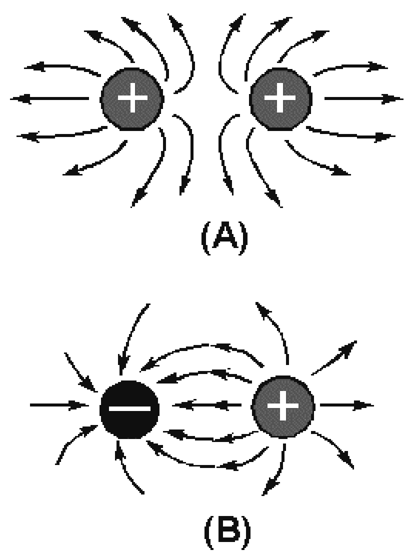

Figure 7—Electrostatic lines of force.

Figure 7(A) represents the repulsion of like-charged bodies and their associated fields. Part (B) represents the attraction of unlike-charged bodies and their associated fields.

Electrical Energy

In the field of physical science, work must be defined as the PRODUCT OF FORCE AND DISPLACEMENT. That is, the force applied to move an object and the distance the object is moved are the factors of work performed.

It is important to notice that no work is accomplished unless the force applied causes a change in the position of a stationary object, or a change in the velocity of a moving object. A worker may tire by pushing against a heavy wooden crate, but unless the crate moves, no work will be accomplished.

ENERGY

In our study of energy and work, we must define energy as THE ABILITY TO DO WORK. In order to perform any kind of work, energy must be expended (converted from one form to another). Energy supplies the required force, or power, whenever any work is accomplished.

One form of energy is that which is contained by an object in motion. When a hammer is set in motion in the direction of a nail, it possesses energy of motion. As the hammer strikes the nail, the energy of motion is converted into work as the nail is driven into the wood. The distance the nail is driven into the wood depends on the velocity of the hammer at the time it strikes the nail. Energy contained by an object due to its motion is called KINETIC ENERGY. Assume that the hammer is suspended by a string in a position one meter above a nail. As a result of gravitational attraction, the hammer will experience a force pulling it downward. If the string is suddenly cut, the force of gravity will pull the hammer downward against the nail, driving it into the wood. While the hammer is suspended above the nail, it has ability to do work because of its elevated position in the earth's gravitational field. Since energy is the ability to do work, the hammer contains energy.

Energy contained by an object due to its position is called POTENTIAL ENERGY. The amount of potential energy available is equal to the product of the force required to elevate the hammer and the height to which it is elevated.

Another example of potential energy is that contained in a tightly coiled spring. The amount of energy released when the spring unwinds depends on the amount of force required to wind the spring initially.

Electrical Charges

From the previous study of electrostatics, you learned that a field of force exists in the space surrounding any electrical charge. The strength of the field is directly dependent on the force of the charge.

The charge of one electron might be used as a unit of electrical charge, since charges are created by displacement of electrons; but the charge of one electron is so small that it is impractical to use. The practical unit adopted for measuring charges is the COULOMB, named after the scientist Charles Coulomb. One coulomb is equal to the charge of 6,250,000,000,000,000,000 (six quintillion two hundred and fifty quadrillion) or (6.25×10^{18}) electrons.

When a charge of one coulomb exists between two bodies, one unit of electrical potential energy exists, which is called the difference of potential between the two bodies. This is referred to as ELECTROMOTIVE FORCE, or VOLTAGE, and the unit of measure is the VOLT.

Electrical charges are created by the displacement of electrons, so that there exists an excess of electrons at one point, and a deficiency at another point. Consequently, a charge must always have either a negative or positive polarity. A body with an excess of electrons is considered to be negative, whereas a body with a deficiency of electrons is positive.

A difference of potential can exist between two points, or bodies, only if they have different charges. In other words, there is no difference in potential between two bodies if both have a deficiency of electrons to the same degree. If, however, one body is deficient of 6 coulombs (representing 6 volts), and the other is deficient by 12 coulombs (representing 12 volts), there is a difference of potential of 6 volts. The body with the greater deficiency is positive with respect to the other.

In most electrical circuits only the difference of potential between two points is of importance and the absolute potentials of the points are of little concern. Very often it is convenient to use one standard reference for all of the various potentials throughout a piece of equipment. For this reason, the potentials at various points in a circuit are generally measured with respect to the metal chassis on which all parts of the circuit are mounted. The chassis is considered to be at zero potential and all other potentials are either positive or negative with respect to the chassis. When used as the reference point, the chassis is said to be at GROUND POTENTIAL.

Occasionally, rather large values of voltage may be encountered, in which case the volt becomes too small a unit for convenience. In this type of situation, the kilovolt (kV), meaning 1,000 volts, is frequently used. As an example, 20,000 volts would be written as 20 kV. In other cases, the volt may be too large a unit, as when dealing with very small voltages. For this purpose the millivolt (mV), meaning one-thousandth of a volt, and the microvolt (µV), meaning one-millionth of a volt, are used. For example, 0.001 volt would be written as 1 mV, and 0.000025 volt would be written as 25 µV.

When a difference in potential exists between two charged bodies that are connected by a conductor, electrons will flow along the conductor. This flow is from the negatively charged body to the positively charged body, until the two charges are equalized and the potential difference no longer exists.

An analogy of this action is shown in the two water tanks connected by a pipe and valve in figure 8. At first the valve is closed and all the water is in tank A. Thus, the water pressure across the valve is at maximum. When the valve is opened, the water flows through the pipe from A to B until the water level becomes the same in both tanks. The water then stops flowing in the pipe, because there is no longer a difference in water pressure between the two tanks.

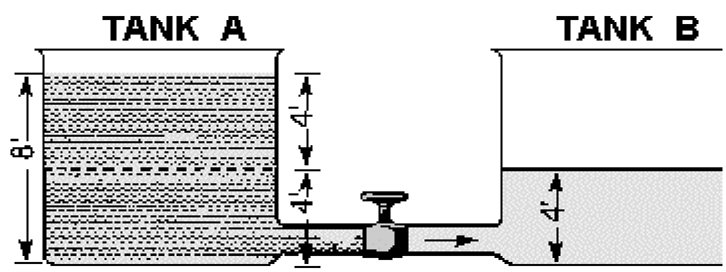

Figure 8 —Water analogy of electric differences of potential.

Electron movement through an electric circuit is directly proportional to the difference in potential or electromotive force (emf), across the circuit, just as the flow of water through the pipe in figure 8 is directly proportional to the difference in water level in the two tanks.

A fundamental law of electricity is that the ELECTRON FLOW IS DIRECTLY PROPORTIONAL TO THE APPLIED VOLTAGE. If the voltage is increased, the flow is increased. If the voltage is decreased, the flow is decreased.

How Voltage is Produced

It has been demonstrated that a charge can be produced by rubbing a rubber rod with fur. Because of the friction involved, the rod acquires electrons from the fur, making it negative; the fur becomes positive due to the loss of electrons. These quantities of charge constitute a difference of potential between the rod and the fur. The electrons that make up this difference of potential are capable of doing work if a discharge is allowed to occur.

To be a practical source of voltage, the potential difference must not be allowed to dissipate, but must be maintained continuously. As one electron leaves the concentration of negative charge, another must be immediately provided to take its place or the charge will eventually diminish to the point where no further work can be accomplished. A VOLTAGE SOURCE, therefore, is a device which is capable of supplying and maintaining voltage while some type of electrical apparatus is connected to its terminals. The internal action of the source is such that electrons are continuously removed from one terminal, keeping it positive, and simultaneously supplied to the second terminal which maintains a negative charge.

Presently, there are six known methods for producing a voltage or electromotive force (emf). Some of these methods are more widely used than others, and some are used mostly for specific applications. Following is a list of the six known methods of producing a voltage.

1. FRICTION—Voltage produced by rubbing certain materials together.
2. PRESSURE (piezoelectricity)—Voltage produced by squeezing crystals of certain substances.
3. HEAT (thermoelectricity)—Voltage produced by heating the joint (junction) where two unlike metals are joined.
4. LIGHT (photoelectricity)—Voltage produced by light striking photosensitive (light sensitive) substances.
5. CHEMICAL ACTION—Voltage produced by chemical reaction in a battery cell.
6. MAGNETISM—Voltage produced in a conductor when the conductor moves through a magnetic field, or a magnetic field moves through the conductor in such a manner as to cut the magnetic lines of force of the field.

Voltage Produced by Friction

The first method discovered for creating a voltage was that of generation by friction. The development of charges by rubbing a rod with fur is a prime example of the way in which a voltage is generated by friction. Because of the nature of the materials with which this voltage is generated, it cannot be conveniently used or maintained. For this reason, very little practical use has been found for voltages generated by this method.

In the search for methods to produce a voltage of a larger amplitude and of a more practical nature, machines were developed in which charges were transferred from one terminal to another by means of rotating glass discs or moving belts. The most notable of these machines is the Van de Graaff generator. It is used today to produce potentials in the order of millions of volts for nuclear research. As these machines have little value outside the field of research, their theory of operation will not be described here.

Voltage Produced by Pressure

One specialized method of generating an emf utilizes the characteristics of certain ionic crystals such as quartz, Rochelle salts, and tourmaline. These crystals have the remarkable ability to generate a voltage whenever stresses are applied to their surfaces. Thus, if a crystal of quartz is squeezed, charges of opposite polarity will appear on two opposite surfaces of the crystal. If the force is reversed and the crystal is stretched, charges will again appear, but will be of the opposite polarity from those produced by squeezing. If a crystal of this type is given a vibratory motion, it will produce a voltage of reversing polarity between two of its sides. Quartz or similar crystals can thus be used to convert mechanical energy into electrical energy. This phenomenon, called the PIEZOELECTRIC EFFECT, is shown in figure 9. Some of the common devices that make use of piezoelectric crystals are microphones, phonograph cartridges, and oscillators used in radio transmitters, radio receivers, and sonar equipment. This method of generating an emf is not suitable for applications having large voltage or power requirements, but is widely used in sound and communications systems where small signal voltages can be effectively used.

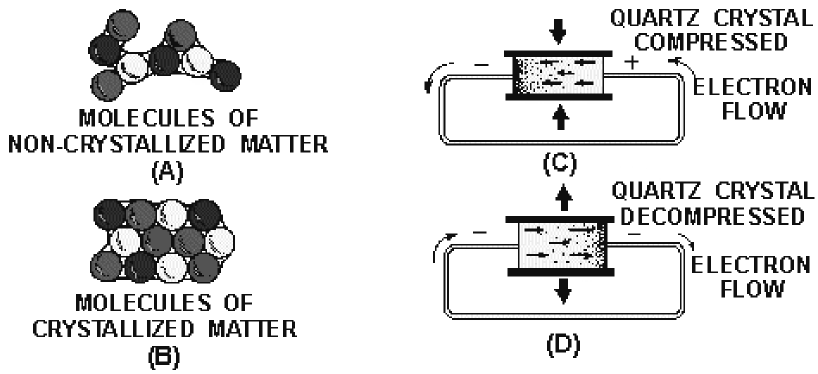

Figure 9.—(A) Noncrystallized structure; (B) crystallized structure; (C) compression of a crystal; (D)decompression of a crystal.

Crystals of this type also possess another interesting property, the "converse piezoelectric effect." That is, they have the ability to convert electrical energy into mechanical energy. A voltage impressed across the proper surfaces of the crystal will cause it to expand or contract its surfaces in response to the voltage applied.

Voltage Produced by Heat

When a length of metal, such as copper, is heated at one end, electrons tend to move away from the hot end toward the cooler end. This is true of most metals. However, in some metals, such as iron, the opposite takes place and electrons tend to move TOWARD the hot end. These characteristics are illustrated in figure 10. The negative charges (electrons) are moving through the copper away from the heat and through the iron toward the heat. They cross from the iron to the copper through the current meter to the iron at the cold junction. This device is generally referred to as a THERMOCOUPLE.

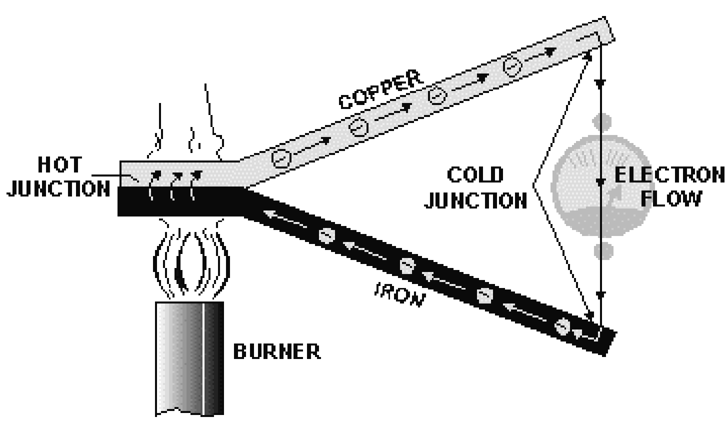

Figure 10.—Voltage produced by heat.

Thermocouples have somewhat greater power capacities than crystals, but their capacity is still very small if compared to some other sources. The thermoelectric voltage in a thermocouple depends mainly on the difference in temperature between the hot and cold junctions. Consequently, they are widely used to measure temperature, and as heat-sensing devices in automatic temperature control equipment. Thermocouples generally can be subjected to much greater temperatures than ordinary thermometers, such as the mercury or alcohol types.

Voltage Produced by Light

When light strikes the surface of a substance, it may dislodge electrons from their orbits around the surface atoms of the substance. This occurs because light has energy, the same as any moving force.

Some substances, mostly metallic ones, are far more sensitive to light than others. That is, more electrons will be dislodged and emitted from the surface of a highly sensitive metal, with a given amount of light, than will be emitted from a less sensitive substance. Upon losing electrons, the photosensitive (light-sensitive) metal becomes positively charged, and an electric force is created. Voltage produced in this manner is referred to as a PHOTOELECTRIC VOLTAGE.

The photosensitive materials most commonly used to produce a photoelectric voltage are various compounds of silver oxide or copper oxide. A complete device which operates on the photoelectric principle is referred to as a "photoelectric cell." There are many different sizes and types of photoelectric cells in use, and each serves the special purpose for which it is designed. Nearly all, however, have some of the basic features of the photoelectric cells shown in figure 11.

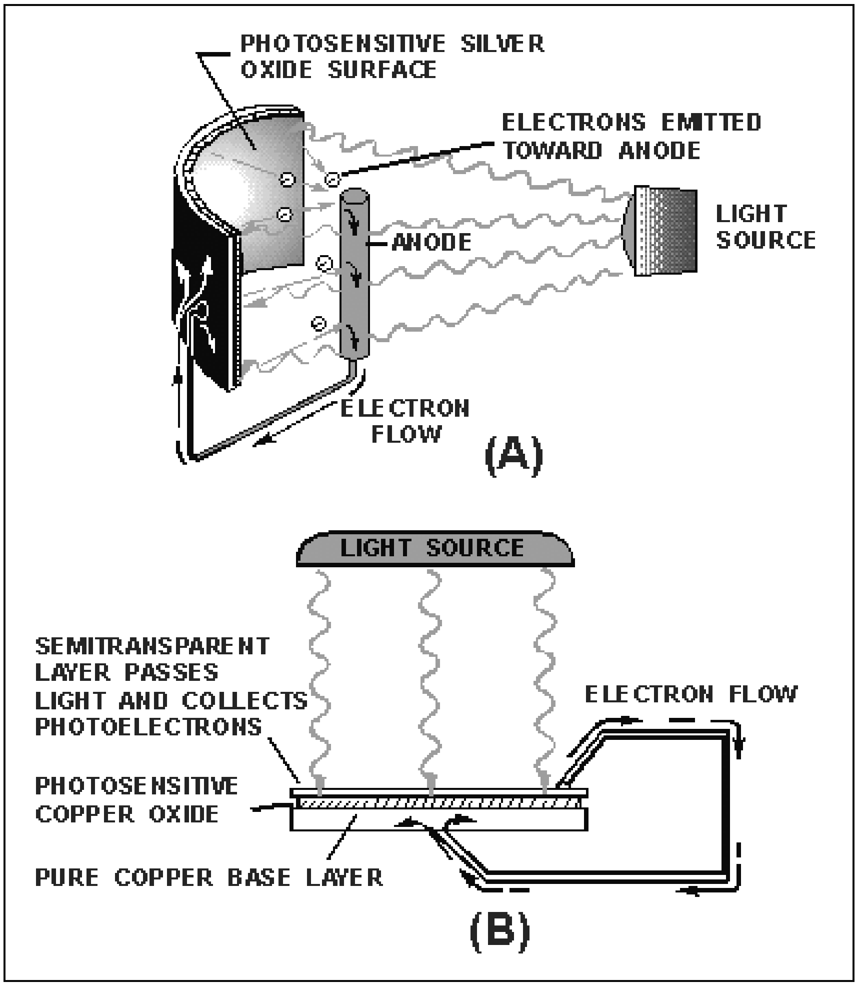

Figure 11.—Voltage produced by light.

The cell (fig. 11 view A) has a curved light-sensitive surface focused on the central anode. When light from the direction shown strikes the sensitive surface, it emits electrons toward the anode. The more intense the light, the greater the number of electrons emitted. When a wire is connected between the filament and the back, or dark side of the cell, the accumulated electrons will flow to the dark side. These electrons will eventually pass through the metal of the reflector and replace the electrons leaving the light-sensitive surface. Thus, light energy is converted to a flow of electrons, and a usable current is developed.

The cell (fig. 11 view B) is constructed in layers. A base plate of pure copper is coated with light- sensitive copper oxide. An extremely thin semitransparent layer of metal is placed over the copper oxide. This additional layer serves two purposes:

1. It permits the penetration of light to the copper oxide.
2. It collects the electrons emitted by the copper oxide.

An externally connected wire completes the electron path, the same as in the reflector-type cell. The photocell's voltage is used as needed by connecting the external wires to some other device, which amplifies (enlarges) it to a usable level.

The power capacity of a photocell is very small. However, it reacts to light-intensity variations in an extremely short time. This characteristic makes the photocell very useful in detecting or accurately controlling a great number of operations. For instance, the photoelectric cell, or some form of the photoelectric principle, is used in television cameras, automatic manufacturing process controls, door openers, burglar alarms, and so forth.

Voltage Produced by Chemical Action

Voltage may be produced chemically when certain substances are exposed to chemical action.
If two dissimilar substances (usually metals or metallic materials) are immersed in a solution that produces a greater chemical action on one substance than on the other, a difference of potential will exist between the two. If a conductor is then connected between them, electrons will flow through the conductor to equalize the charge. This arrangement is called a primary cell. The two metallic pieces are called electrodes and the solution is called the electrolyte. The voltaic cell illustrated in figure 12 is a simple example of a primary cell. The difference of potential results from the fact that material from one or both of the electrodes goes into solution in the electrolyte, and in the process, ions form in the vicinity of the electrodes. Due to the electric field associated with the charged ions, the electrodes acquire charges.

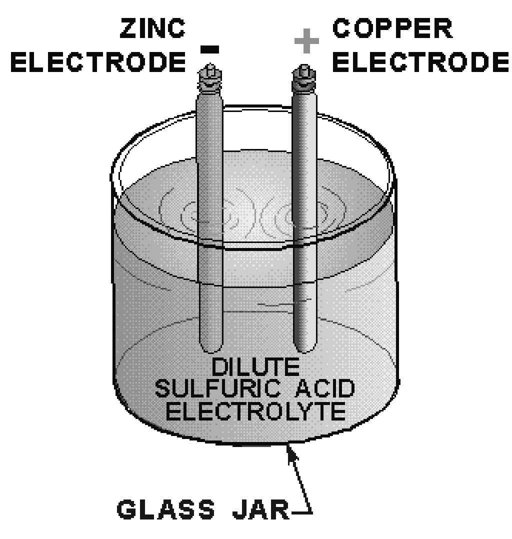

Figure 12.—Voltaic cell.

The amount of difference in potential between the electrodes depends principally on the metals used. The type of electrolyte and the size of the cell have little or no effect on the potential difference produced.

There are two types of primary cells, the wet cell and the dry cell. In a wet cell the electrolyte is a liquid. A cell with a liquid electrolyte must remain in an upright position and is not readily transportable. The dry cell, much more commonly used than the wet cell, is not actually dry, but contains an electrolyte mixed with other materials to form a paste. Flashlights and portable radios are commonly powered by dry cells. Batteries are formed when several cells are connected together to increase electrical output.

Voltage Produced by Magnetism

Magnets or magnetic devices are used for thousands of different jobs. One of the most useful and widely employed applications of magnets is in the production of vast quantities of electric power from mechanical sources. The mechanical power may be provided by a number of different sources, such as gasoline or diesel engines, and water or steam turbines. However, the final conversion of these source energies to electricity is done by generators employing the principle of electromagnetic induction. These generators, of many types and sizes, are discussed in other modules in this series. The important subject to be discussed here is the fundamental operating principle of ALL such electromagnetic-induction generators.

To begin with, there are three fundamental conditions that must exist before a voltage can be produced by magnetism.

1. There must be a CONDUCTOR in which the voltage will be produced.
2. There must be a MAGNETIC FIELD in the conductor's vicinity.
3. There must be relative motion between the field and conductor. The conductor must be moved to cut across the magnetic lines of force, or the field must be moved so that the lines of force are cut by the conductor.

In accordance with these conditions, when a conductor or conductors MOVE ACROSS a magnetic field so as to cut the lines of force, electrons WITHIN THE CONDUCTOR are propelled in one direction or another. Thus, an electric force, or voltage, is created.

In figure 13, note the presence of the three conditions needed for creating an induced voltage.

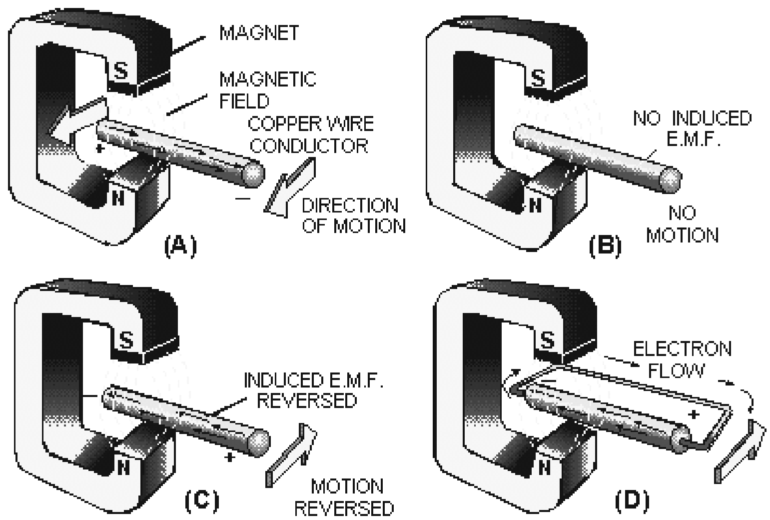

Figure 13.—Voltage produced by magnetism.

1. A magnetic field exists between the poles of the C-shaped magnet.
2. There is a conductor (copper wire).
3. There is a relative motion. The wire is moved back and forth ACROSS the magnetic field.

In figure 13 view A, the conductor is moving TOWARD the front of the page and the electrons move from left to right. The movement of the electrons occurs because of the magnetically induced emf acting on the electrons in the copper. The right-hand end becomes negative, and the left-hand end positive. The conductor is stopped at view B, motion is eliminated (one of the three required conditions), and there is no longer an induced emf. Consequently, there is no longer any difference in potential between the two ends of the wire. The conductor at view C is moving away from the front of the page. An induced emf is again created. However, note carefully that the REVERSAL OF MOTION has caused a REVERSAL OF DIRECTION in the induced emf.

If a path for electron flow is provided between the ends of the conductor, electrons will leave the negative end and flow to the positive end. This condition is shown in part view D. Electron flow will continue as long as the emf exists. In studying figure 13, it should be noted that the induced emf could also have been created by holding the conductor stationary and moving the magnetic field back and forth.

ELECTRIC CURRENT

It has been proven that electrons (negative charges) move through a conductor in response to an electric field. ELECTRON CURRENT FLOW will be used throughout this explanation. Electron current is defined as the directed flow of electrons. The direction of electron movement is from a region of negative potential to a region of positive potential. Therefore electric current can be said to flow from negative to positive. The direction of current flow in a material is determined by the polarity of the applied voltage. NOTE: In some electrical/electronic communities, the direction of current flow is recognized as being from positive to negative. This is referred to as conventional flow.

Random Drift

All materials are composed of atoms, each of which is capable of being ionized. If some form of energy, such as heat, is applied to a material, some electrons acquire sufficient energy to move to a higher energy level. As a result, some electrons are freed from their parent atom which then becomes ions. Other forms of energy, particularly light or an electric field will cause ionization to occur.

The number of free electrons resulting from ionization is dependent upon the quantity of energy applied to a material, as well as the atomic structure of the material. At room temperature some materials, classified as conductors, have an abundance of free electrons. Under a similar condition, materials classified as insulators have relatively few free electrons.

In a study of electric current, conductors are of major concern. Conductors are made up of atoms that contain loosely bound electrons in their outer orbits. Due to the effects of increased energy, these outermost electrons frequently break away from their atoms and freely drift throughout the material. The free electrons, also called mobile electrons, take a path that is not predictable and drift about the material in a haphazard manner. Consequently, such a movement is termed RANDOM DRIFT.

It is important to emphasize that the random drift of electrons occurs in all materials. The degree of random drift is greater in a conductor than in an insulator.

Directed Drift

Associated with every charged body there is an electrostatic field. Bodies that are charged alike repel one another and bodies with unlike charges attract each other. An electron will be affected by an electrostatic field in exactly the same manner as any negatively charged body. It is repelled by a negative charge and attracted by a positive charge. If a conductor has a difference in potential impressed across it, as shown in figure 14, a direction is imparted to the random drift. This causes the mobile electrons to be repelled away from the negative terminal and attracted toward the positive terminal. This constitutes a general migration of electrons from one end of the conductor to the other. The directed migration of mobile electrons due to the potential difference is called DIRECTED DRIFT.

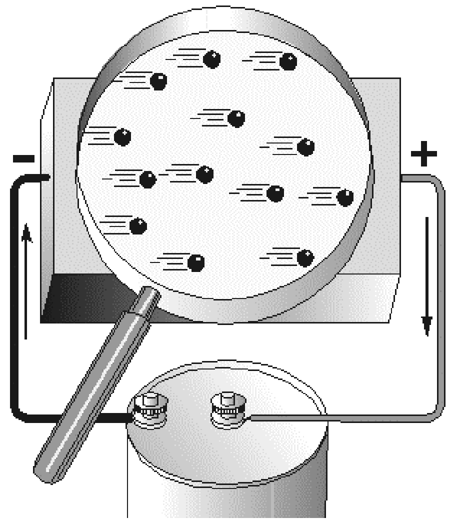

Figure 14.—Directed drift.

The directed movement of the electrons occurs at a relatively low VELOCITY (rate of motion in a particular direction). The effect of this directed movement, however, is felt almost instantaneously, as explained by the use of figure 15. As a difference in potential is impressed across the conductor, the positive terminal of the battery attracts electrons from point A. Point A now has a deficiency of electrons. As a result, electrons are attracted from point B to point A. Point B has now developed an electron deficiency, therefore, it will attract electrons. This same effect occurs throughout the conductor and repeats itself from points D to C. At the same instant the positive battery terminal attracted electrons from point A, the negative terminal repelled electrons toward point D. These electrons are attracted to point D as it gives up electrons to point C. This process is continuous for as long as a difference of potential exists across the conductor. Though an individual electron moves quite slowly through the conductor, the effect of a directed drift occurs almost instantaneously. As an electron moves into the conductor at point D, an electron is leaving at point A. This action takes place at approximately the speed of light (186,000 miles per second).

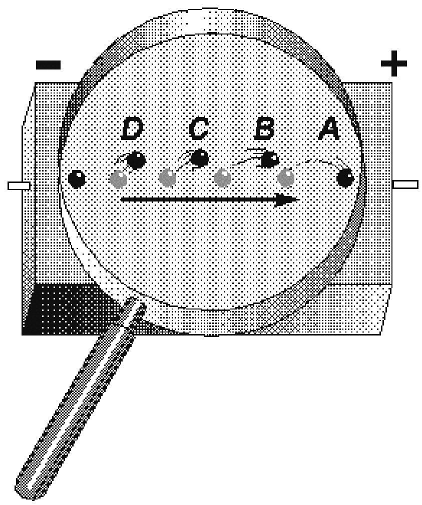

Figure 15.—Effect of directed drift. Magnitude of Current Flow

Electric current has been defined as the directed movement of electrons. Directed drift, therefore, is current and the terms can be used interchangeably. The expression directed drift is particularly helpful in differentiating between the random and directed motion of electrons. However, CURRENT FLOW is the terminology most commonly used in indicating a directed movement of electrons.

The magnitude of current flow is directly related to the amount of energy that passes through a conductor as a result of the drift action. An increase in the number of energy carriers (the mobile electrons) or an increase in the energy of the existing mobile electrons would provide an increase in current flow. When an electric potential is impressed across a conductor, there is an increase in the velocity of the mobile electrons causing an increase in the energy of the carriers. There is also the generation of an increased number of electrons providing added carriers of energy. The additional number of free electrons is relatively small; hence the magnitude of current flow is primarily dependent on the velocity of the existing mobile electrons.

The magnitude of current flow is affected by the difference of potential in the following manner. Initially, mobile electrons are given additional energy because of the repelling and attracting electrostatic field. If the potential difference is increased, the electric field will be stronger, the amount of energy imparted to a mobile electron will be greater, and the current will be increased. If the potential difference is decreased, the strength of the field is reduced, the energy supplied to the electron is diminished, and the current is decreased.

Measurement of Current

The magnitude of current is measured in AMPERES. A current of one ampere is said to flow when one coulomb of charge passes a point in one second. Remember, one coulomb is equal to the charge of 6.25×10^{18} electrons.

Frequently, the ampere is much too large a unit for measuring current. Therefore, the MILLIAMPERE (mA), one-thousandth of an ampere, or the MICROAMPERE (µA), one-millionth of an ampere, is used. The device used to measure current is called an AMMETER and will be discussed in detail in a later module.

ELECTRICAL RESISTANCE

It is known that the directed movement of electrons constitutes a current flow. It is also known that the electrons do not move freely through a conductor's crystalline structure. Some materials offer little opposition to current flow, while others greatly oppose current flow. This opposition to current flow is known as RESISTANCE (R), and the unit of measure is the OHM. The standard of measure for one ohm is the resistance provided at zero degrees Celsius by a column of mercury having a cross-sectional area of one square millimeter and a length of 106.3 centimeters. A conductor has one ohm of resistance when an applied potential of one volt produces a current of one ampere. The symbol used to represent the ohm is the Greek letter omega (Ω).

Resistance, although an electrical property, is determined by the physical structure of a material. The resistance of a material is governed by many of the same factors that control current flow. Therefore, in a subsequent discussion, the factors that affect current flow will be used to assist in the explanation of the factors affecting resistance.

Factors That Affect Resistance

The magnitude of resistance is determined in part by the "number of free electrons" available within the material. Since a decrease in the number of free electrons will decrease the current flow, it can be said that the opposition to current flow (resistance) is greater in a material with fewer free electrons. Thus, the resistance of a material is determined by the number of free electrons available in a material.

A knowledge of the conditions that limit current flow and, therefore, affect resistance can now be used to consider how the type of material, physical dimensions, and temperature will affect the resistance of a conductor.

TYPE OF MATERIAL.—Depending upon their atomic structure, different materials will have different quantities of free electrons. Therefore, the various conductors used in electrical applications have different values of resistance.

Consider a simple metallic substance. Most metals are crystalline in structure and consist of atoms that are tightly bound in the lattice network. The atoms of such elements are so close together that the electrons in the outer shell of the atom are associated with one atom as much as with its neighbor. (See fig. 16 view A). As a result, the force of attachment of an outer electron with an individual atom is practically zero. Depending on the metal, at least one electron, sometimes two, and in a few cases, three electrons per atom exist in this state. In such a case, a relatively small amount of additional electron energy would free the outer electrons from the attraction of the nucleus. At normal room temperature materials of this type have many free electrons and are good conductors. Good conductors will have a low resistance.

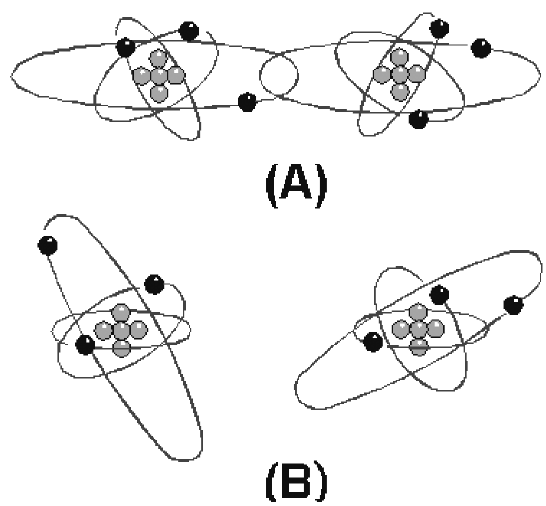

Figure 16.—Atomic spacing in conductors.

If the atoms of a material are farther apart, as illustrated in figure 16 view B, the electrons in the outer shells will not be equally attached to several atoms as they orbit the nucleus. They will be attracted by the nucleus of the parent atom only. Therefore, a greater amount of energy is required to free any of these electrons. Materials of this type are poor conductors and therefore have a high resistance. Silver, gold, and aluminum are good conductors. Therefore, materials composed of their atoms would have a low resistance.

The element copper is the conductor most widely used throughout electrical applications. Silver has a lower resistance than copper but its cost limits usage to circuits where a high conductivity is demanded. Aluminum, which is considerably lighter than copper, is used as a conductor when weight is a major factor.

EFFECT OF CROSS-SECTIONAL AREA.—Cross-sectional area greatly affects the magnitude of resistance. If the cross-sectional area of a conductor is increased, a greater quantity of electrons is available for movement through the conductor. Therefore, a larger current will flow for a given amount of applied voltage. An increase in current indicates that when the cross-sectional area of a conductor is increased, the resistance must have decreased. If the cross-sectional area of a conductor is decreased, the number of available electrons decreases and, for a given applied voltage, the current through the conductor decreases. A decrease in current flow indicates that when the cross-sectional area of a conductor is decreased, the resistance must have increased. Thus, the RESISTANCE OF A CONDUCTOR IS INVERSELY PROPORTIONAL TO ITS CROSS-SECTIONAL AREA.

The diameter of conductors used in electronics is often only a fraction of an inch; therefore, the diameter is expressed in mils (thousandths of an inch). It is also standard practice to assign the unit circular mil to the cross-sectional area of the conductor. The circular mil is found by squaring the diameter when the diameter is expressed in mils. Thus, if the diameter is 35 mils (0.035 inch), the circular mil area is equal to $(35)^2$ or 1225 circular mils. A comparison between a square mil and a circular mil is illustrated in figure 17.

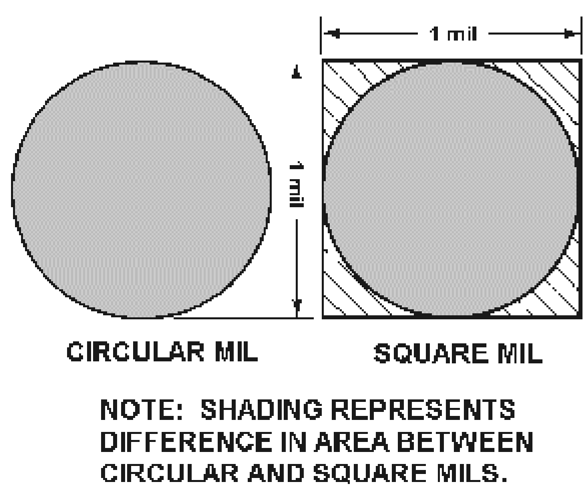

Figure 17.—Square and circular mils.

EFFECT OF CONDUCTOR LENGTH.—The length of a conductor is also a factor which determines the resistance of a conductor. If the length of a conductor is increased, the amount of energy given up increases. As free electrons move from atom to atom some energy is given off as heat. The longer a conductor is the more energy is lost to heat. The additional energy loss subtracts from the energy being transferred through the conductor, resulting in a decrease in current flow for a given applied voltage. A decrease in current flow indicates an increase in resistance, since voltage was held constant. Therefore, if the length of a conductor is increased, the resistance increases. THE RESISTANCE OF CONDUCTOR IS DIRECTLY PROPORTIONAL TO ITS LENGTH.

EFFECT OF TEMPERATURE.—Temperature changes affect the resistance of materials in different ways. In some materials an increase in temperature causes an increase in resistance, whereas in others, an increase in temperature causes a decrease in resistance. The amount of change of resistance per unit change in temperature is known as the TEMPERATURE COEFFICIENT. If for an increase in temperature the resistance of a material increases, it is said to have a POSITIVE TEMPERATURE COEFFICIENT. A material whose resistance decreases with an increase in temperature has a NEGATIVE TEMPERATURE COEFFICIENT. Most conductors used in electronic applications have a positive temperature coefficient. However, carbon, a frequently used material, is a substance having a negative temperature coefficient. Several materials, such as the alloys constantan and manganin, are considered to have a ZERO TEMPERATURE COEFFICIENT because their resistance remains relatively constant for changes in temperature.

CONDUCTANCE

Electricity is a study that is frequently explained in terms of opposites. The term that is the opposite of resistance is CONDUCTANCE. Conductance is the ability of a material to pass electrons. The factors that affect the magnitude of resistance are exactly the same for conductance, but they affect conductance in the opposite manner. Therefore, conductance is directly proportional to area, and inversely proportional to the length of the material. The temperature of the material is definitely a factor, but assuming a constant temperature, the conductance of a material can be calculated.

The unit of conductance is the MHO (G), which is ohm spelled backwards. Recently the term mho has been redesignated SIEMENS (S). Whereas the symbol used to represent resistance (R) is the Greek letter omega (Ω), the symbol used to represent conductance (G) is (S). The relationship that exists between resistance (R) and conductance (G) or (S) is a reciprocal one. A reciprocal of a number is one divided by that number. In terms of resistance and conductance:

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

ELECTRICAL SAFETY

Safety precautions must always be observed by persons working around electric circuits and equipment to avoid injury from electric shock. The danger of shock from a high voltage electrical system is well recognized. This is shown by the relatively low number of reports of serious shock received from this voltage, despite its widespread use. On the other hand, a number of fatalities have been reported due to contact with low-voltage circuits. Despite a fairly widespread, but totally unfounded, popular belief to the contrary, low-voltage circuits (115 volts and below) are very dangerous and can cause death when the resistance of the body is lowered. Fundamentally, current, rather than voltage, is the measure of shock intensity. The passage of even a very small current through a vital part of the human body can cause DEATH. The voltage necessary to produce the fatal current is dependent upon the resistance of the body, contact conditions, the path through the body, etc. For example, when a 60-hertz alternating current, is passed through a human body from hand to hand or from hand to foot, and the current is gradually increased, it will cause the following effects: At about 1 milliampere (0.001 ampere), the shock can be felt; at about 10 milliamperes (0.01 ampere), the shock is of sufficient intensity to prevent voluntary control of the muscles; and at about 100 milliamperes (0.1 ampere) the shock is fatal if it lasts for 1 second or more. The above figures are the results of numerous investigations and are approximate because individuals differ in their resistance to electrical shock. It is most important to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from 115 volts or less— FATALITIES FROM VOLTAGES AS LOW AS 30 VOLTS HAVE BEEN RECORDED. Tests have shown that body resistance under unfavorable conditions may be as low as 300 ohms, and possibly as low as 100 ohms from temple to temple if the skin is broken.

ALL LIVE ELECTRIC CIRCUITS SHALL BE TREATED AS POTENTIAL HAZARDS AT ALL TIMES.

DANGER SIGNALS

Technicians should constantly be on the alert for any signs which might indicate a malfunction of electric equipment. Besides the more obvious visual signs, the reaction of other senses, such as hearing, smell, and touch, should also make you aware of possible electrical malfunctions. Examples of signs which you must be alert for are: fire, smoke, sparks, arcing, or an unusual sound from an electric motor. Frayed and damaged cords or plugs; receptacles, plugs, and cords which feel warm to the touch; slight shocks felt when handling electrical equipment; unusually hot running electric motors and other electrical equipment; an odor of burning or overheated insulation; electrical equipment which either fails to operate or operates irregularly; and electrical equipment which produces excessive vibrations are also indications of malfunctions. When any of the above signs are noted, they are to be reported immediately to a qualified technician. DO NOT DELAY. Do not operate faulty equipment. Above all, do not attempt to make any repairs yourself if you are not qualified to do so. Stand clear of any suspected hazard and instruct others to do likewise.

- **Warning Signs**—They have been placed for your protection. To disregard them is to invite personal injury as well as possible damage to equipment. Switches and receptacles with a temporary warning tag, indicating work is being performed, are not to be touched.

- **Working Near Electrical Equipment**—When work must be performed in the immediate vicinity of electrical equipment, check with the technician responsible for the maintenance of the equipment so you can avoid any potential hazards of which you may not be immediately aware.

- **Authorized Personnel Only**—Because of the danger of fire, damage to equipment, and injury to personnel, all repair and maintenance work on electrical equipment shall be done only by authorized persons. Keep your hands off of all equipment which you have not been specifically authorized to handle. Particularly stay clear of electrical equipment opened for inspection, testing, or servicing.

- **Circuit Breakers and Fuses**—Covers for all fuse boxes, junction boxes, switch boxes, and wiring accessories should be kept closed. Any cover which is not closed or is missing should be reported to the technician responsible for its maintenance. Failure to do so may result in injury to personnel or damage to equipment in the event accidental contact is made with exposed live circuits.

ELECTRICAL FIRES

Carbon dioxide (CO_2) is used in fighting electrical fires. It is nonconductive and, therefore, the safest to use in terms of electrical safety. It also offers the least likelihood of damaging equipment. However, if the discharge horn of a CO_2 extinguisher is allowed to touch an energized circuit, the horn may transmit a shock to the person handling the extinguisher.

The very qualities which cause CO_2 to be a valuable extinguishing agent also make it dangerous to life. When it replaces oxygen in the air to the extent that combustion cannot be sustained, respiration also cannot be sustained. Exposure of a person to an atmosphere of high concentration of CO_2 will cause suffocation.

FIRST AID FOR ELECTRIC SHOCK

A person who has stopped breathing is not necessarily dead, but is in immediate danger. Life is dependent upon oxygen, which is breathed into the lungs and then carried by the blood to every cell in the body. Since body cells cannot store oxygen, and since the blood can hold only a limited amount (and that only for a short time), death will surely result from continued lack of breathing.

However, the heart may continue to beat for some time after breathing has stopped, and the blood may still be circulated to the body cells. Since the blood will, for a short time, contain a small supply of oxygen, the body cells will not die immediately. For a very few minutes, there is some chance that the person's life may be saved.

In the event of an electrical accident, the first response should be to call for emergency aid. The only logical, permissible delay is that required to free the victim from contact with the electricity in the quickest, safest way. This step, while it must be taken quickly, must be done with great care; otherwise, there may be two victims instead of one. In the case of portable electric tools, lights, appliances, equipment, or portable outlet extensions, this should be done by turning off the supply switch or by removing the plug from its receptacle. If the switch or receptacle cannot be quickly located, the suspected electrical device may be pulled free of the victim. Other persons arriving on the scene must be clearly warned not to touch the suspected equipment until it is deenergized. Aid should be enlisted to unplug the device as soon as possible. The injured person should be pulled free of contact with stationary equipment.

This can be done quickly and safely by carefully applying the following procedures:

- Protect yourself with dry insulating material.
- Use a dry board, belt, clothing, or other available nonconductive material to free the victim from electrical contact. DO NOT TOUCH THE VICTIM UNTIL THE SOURCE OF ELECTRICITY HAS BEEN REMOVED.
- Once the victim has been removed from the electrical source, it should be determined, if the person is breathing. If the person is not breathing, a method of artificial ventilation is used.

Sometimes victims of electrical shock suffer cardiac arrest (heart stoppage) as well as loss of breathing. A technique known as Cardiopulmonary Resuscitation (CPR) has been developed to provide aid to a person who has stopped breathing and suffered a cardiac arrest. In addition, CPR should be performed only by those who are qualified to do so. It is important to familiarize yourself with the emergency procedures of your shop as it is very likely there are personnel who are specially trained as first responders.

You should, at your earliest opportunity, learn the technique of CPR. CPR is relatively easy to learn and is taught in courses available from the American Red Cross or from the local fire department.

References

United States Navy. (1998). *Navy Electricity and Electronics Training Series - Module 1 Introduction to Matter, Energy, and Direct Current.* (ETCS(SW) Donnie Jones, Ed.) Pensacola, Florida, USA: Naval Education and Training Professional Development and Technology Center. pp 3-13; 25-40; 108-111.