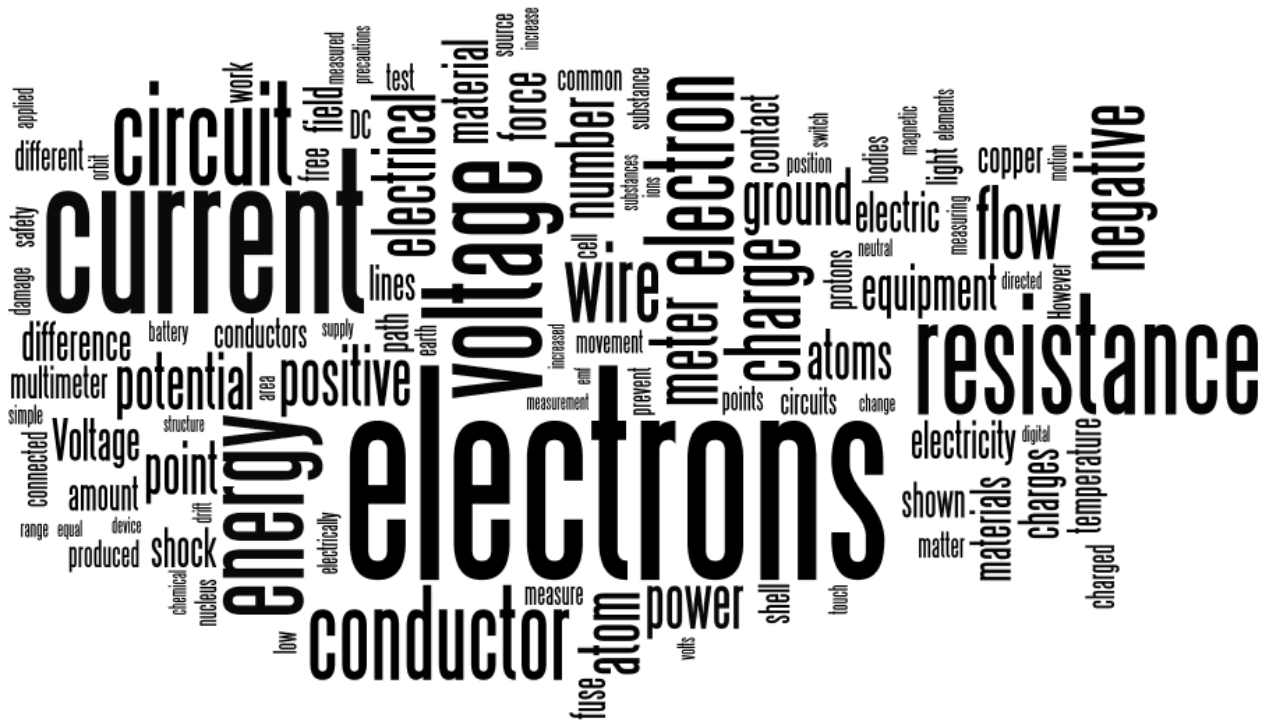


1 Electricity

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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 explains 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

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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.

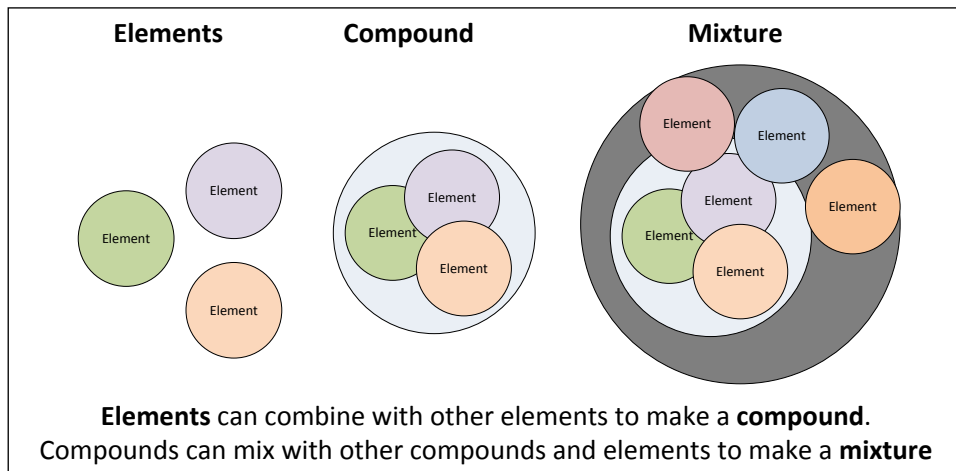


Figure 1: Elements, Compound, and Mixture

Molecules

A **molecule** is a chemical combination of two or more atoms, (atoms are described below). 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

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divided, instead of two parts of water, there will be one part of oxygen and two parts of hydrogen (H₂O).

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

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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 2 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.

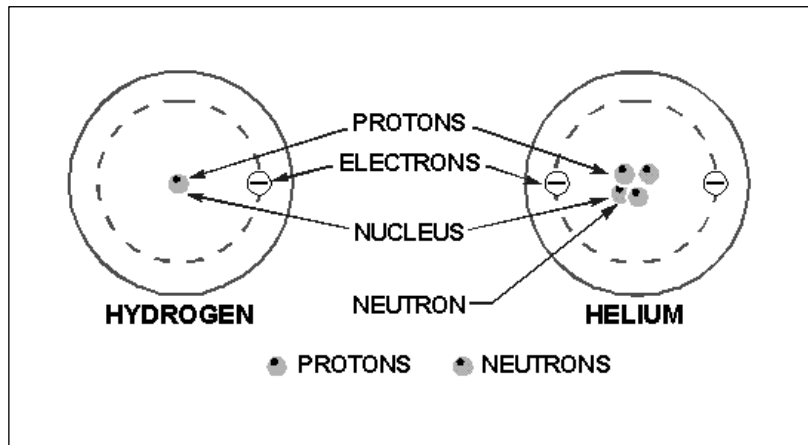


Figure 2: Structures of simple atoms

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 3. The electron, which now has a greater than normal amount of energy, will jump to a new orbit farther from the nucleus.

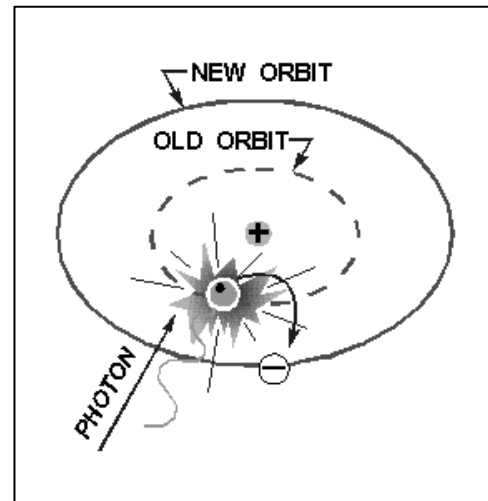


Figure 3: Excitation by a photon.

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.

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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**

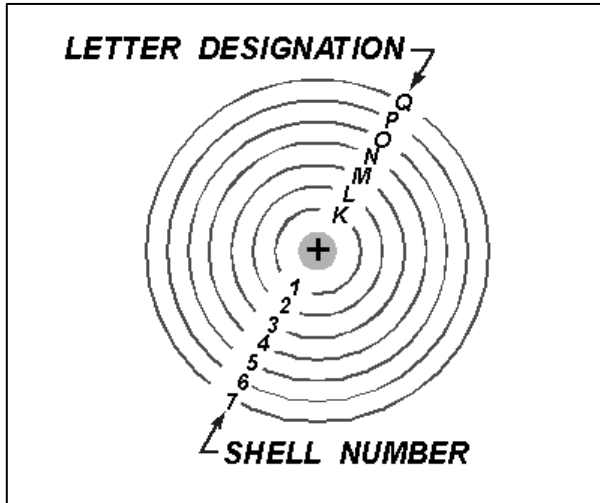


Figure 4: Shell designations.

In addition to being numbered, the shells are also given letter designations, as pictured in Figure 4. 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.

exclusion principle. Simply stated, this principle specifies that each shell will contain a maximum of no 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.

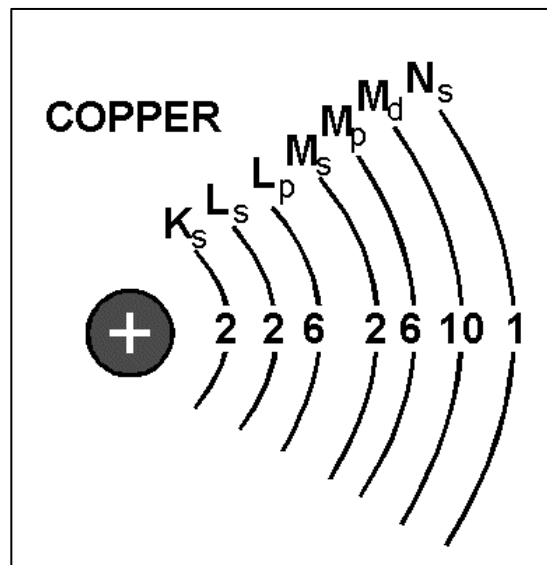


Figure 5: Copper atom.

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

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shell. Notice the electron configuration for copper illustrated in Figure 5. 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.

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

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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.

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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.

Name	Description	Examples
Conductors	Elements that readily conduct the flow of energy	Silver, copper, gold, aluminum
Insulators	Elements with high resistance to the flow of energy	Rubber, plastic, enamel, glass, dry wood, mica
Semiconductors	Elements that are in between these extremes.	Silicon, germanium,

Table 1: Conductors, Insulators, and Semiconductors

Knowledge Check

1. True or False. Anything that occupies space and has weight is matter.
2. True or False. An element is a substance which cannot be reduced to a simpler substance by chemical means.
3. Match the type of subatomic particle to the correct charge.

proton	negative
electron	neutral
neutron	positive

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 and 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

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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

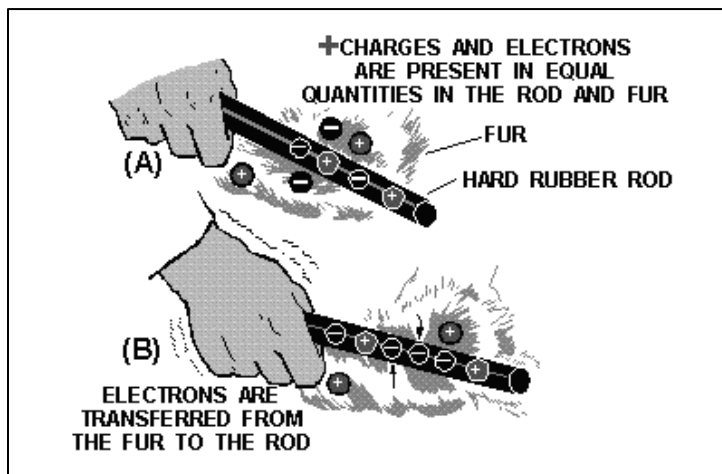


Figure 6: Producing static electricity by friction.

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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 6. 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.

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 7

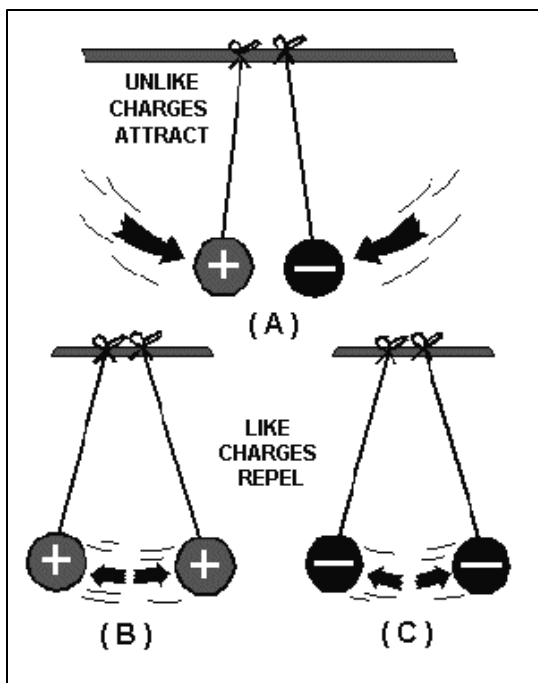


Figure 7: Reaction between charged bodies.

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 7(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 7(C). If a positive or a negative charge is placed on both balls (Figure 7(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** is stated below.

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 8 illustrates the use of lines to represent the field about charged bodies.

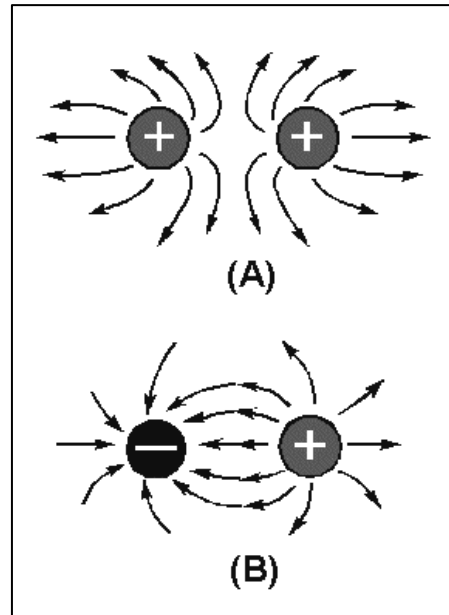


Figure 8: Electrostatic lines of force.

Figure 8(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.

Knowledge Check

4. True or False. A negative charge is created in a neutral body by the accumulation of excess protons.
5. True or False. Static charge is the result of friction.
6. The electrical charge of an atom which contains 8 protons and 11 electrons is:
 - a. positive.
 - b. negative.
 - c. neutral.
7. What is the electrical charge of an atom which contains 4 protons and 4 electrons?
 - a. Positive
 - b. Negative
 - c. Neutral
8. True or False. Like charges attract and unlike charges repel.

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.

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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 (C)**, 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 (emf), or voltage**, and the unit of measure is the **volt (V)**.

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.

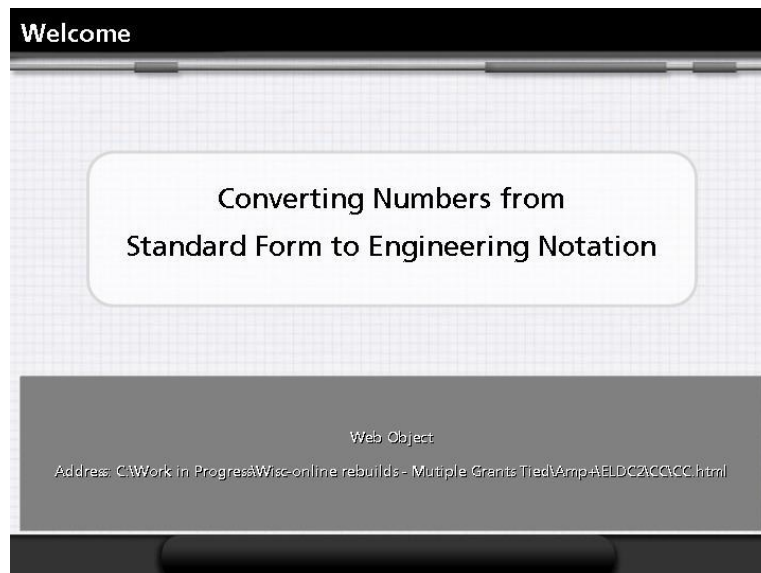
A difference of potential can exist between two points, or bodies, only if they have different charges. In other words, there is no difference in potential between two bodies if both have a deficiency of electrons to the same degree. If, however, one body is deficient of 6 coulombs (representing 6 volts),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

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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 .

Memory Jogger – How to Convert Standard Form to Engineering Notation



Video 1: Converting Numbers from Standard Form to Engineering Notation

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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 9. 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.

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 9 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.

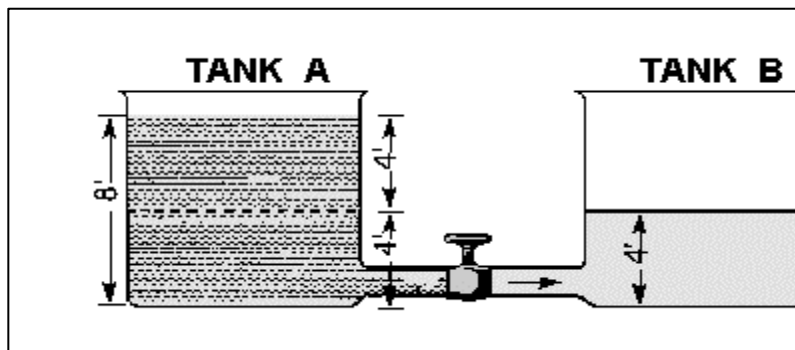


Figure 9: Water analogy of electrical differences of potential.

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

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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.

- **FRICION**—Voltage produced by rubbing certain materials together.
- **PRESSURE** (piezoelectricity)—Voltage produced by squeezing crystals of certain substances.
- **HEAT** (thermoelectricity)—Voltage produced by heating the joint (junction) where two unlike metals are joined.
- **LIGHT** (photoelectricity)—Voltage produced by light striking photosensitive (light sensitive) substances.
- **CHEMICAL ACTION**—Voltage produced by chemical reaction in a battery cell.
- **MAGNETISM** — Voltage produced by 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

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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 10. 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.

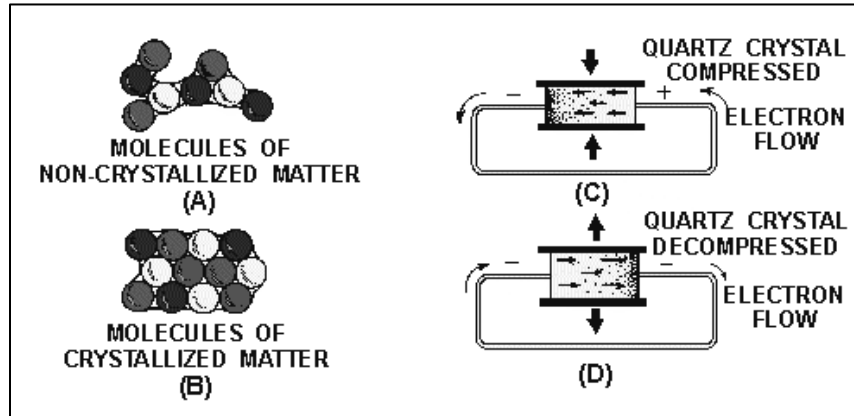


Figure 10: (A) Non-crystallized structure; (B) crystallized structure; (C) compression of a crystal; (D) decompression of a crystal.

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 11. 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**.

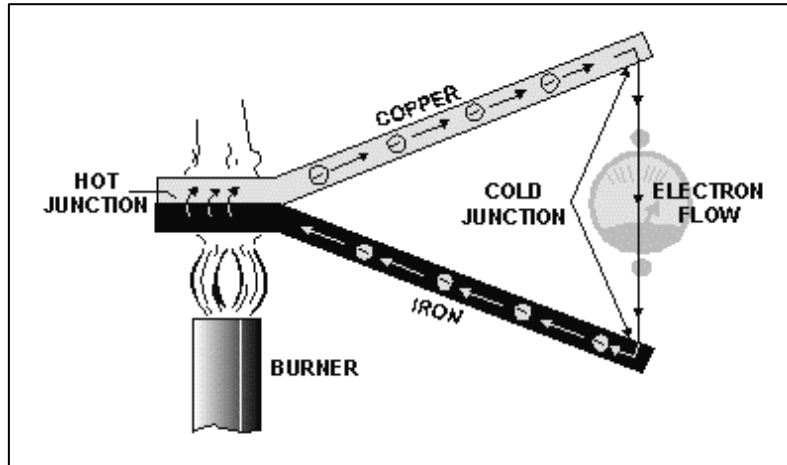


Figure 11: Voltage produced by heat.

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 **photoelectric**.

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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 12.

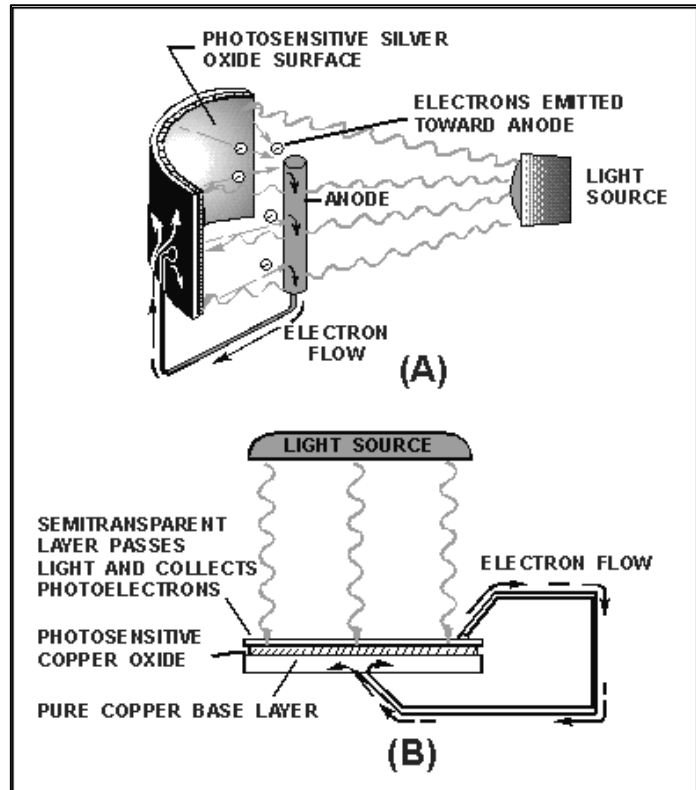


Figure 12: Voltage produced by light.

The cell (Figure 12 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 (Figure 12 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:

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

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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 13 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. 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.

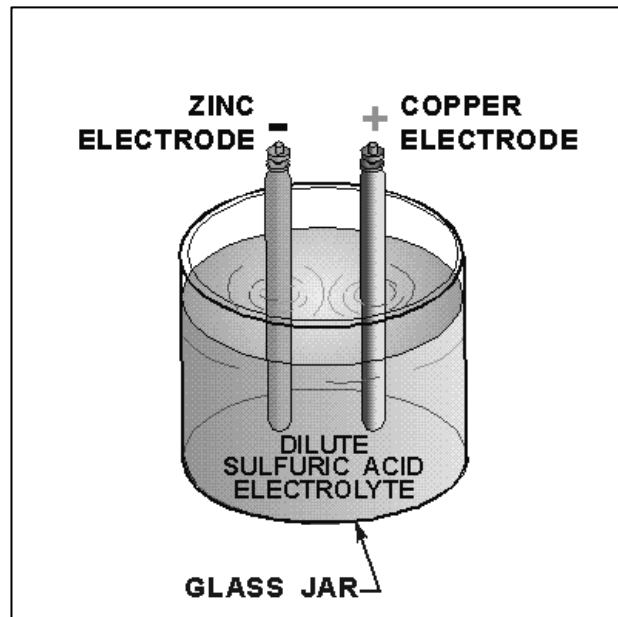


Figure 13: Voltaic Cell

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.

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To begin with, there are three fundamental conditions that must exist before a voltage can be produced by magnetism. First, there must be a magnetic field in the conductor's vicinity. Next, there must be a conductor in which the voltage will be produced. And finally, 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.

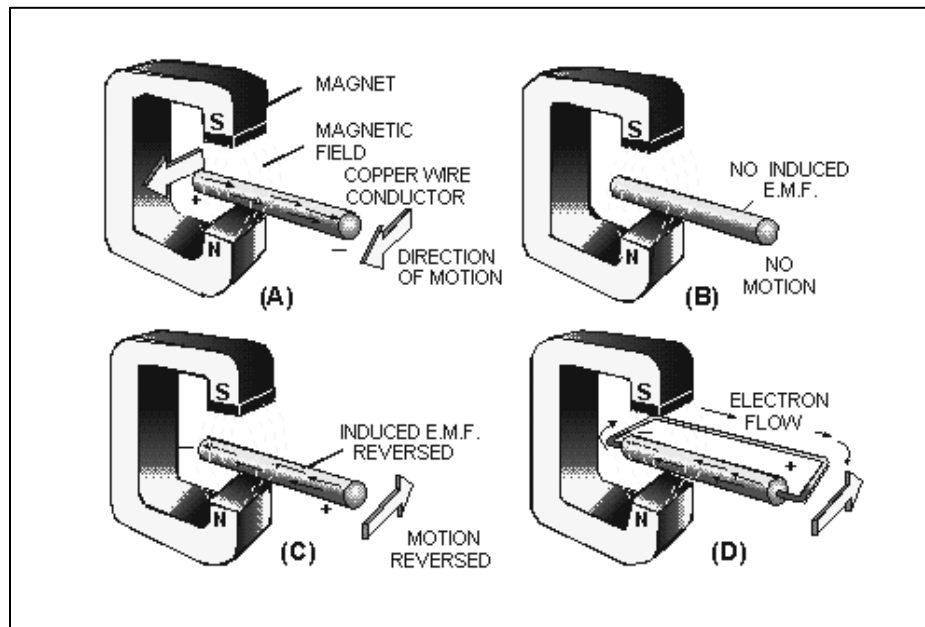


Figure 14: Voltage produced by magnetism.

Note the three fundamental conditions that must exist before a voltage can be produced by magnetism as indicated in Figure 14:

4. There must be a magnetic field in the conductor's vicinity.
 - a. A magnetic field exists between the poles of the C-shaped magnet.

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5. There must be a conductor in which the voltage will be produced.
 - b. There is a conductor (copper wire).
6. 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.
 - c. There is a relative motion. The wire is moved back and forth *across* the magnetic field.

In Figure 14 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 14, 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.

Knowledge Check

9. Choose the term which most accurately describes voltage or emf.

- a. Resistance
- b. Current
- c. Difference of Potential

10. 3900 volts is the same as:

- d. 3.9 mV
- e. 39 mV
- f. 3.9 kV
- g. 39 kV

11. Match the voltage type to the example of how it is produced.

Piezoelectric	Chemical
Generator	Heat
Battery	Light
Thermocouple	Magnetic
Photoelectric	Pressure

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 Current 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**.

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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 15, a direction is imparted to the random drift. This causes the mobile

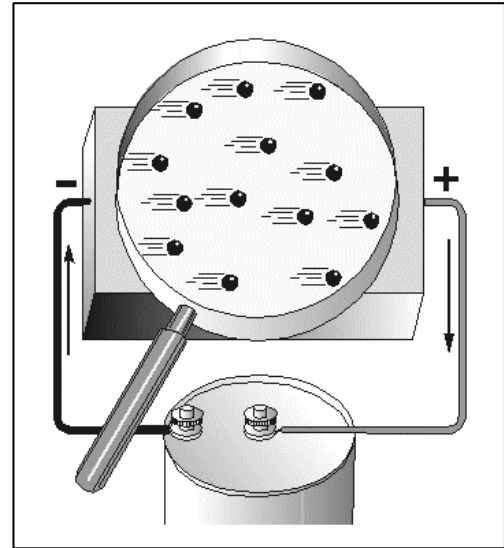


Figure 15: Directed drift.

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**.

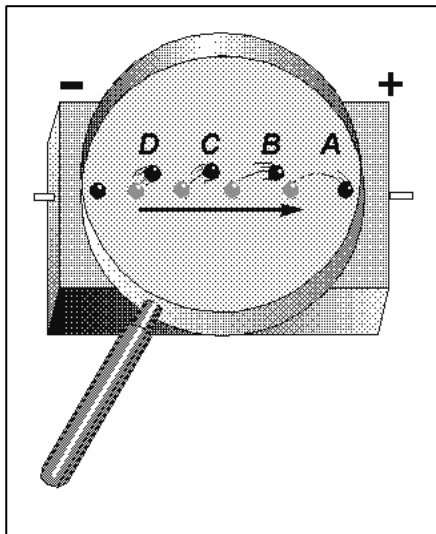


Figure 16: Effect of directed drift.

Magnitude of Current Flow

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 16. 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

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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).

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). 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** (μ A), one-millionth of an ampere, is used. The device used to measure current is called an **ammeter** and will be discussed in detail later.

Knowledge Check

12. True or False. According to electron theory (Electron Current Flow), an electric current flows from the negative potential to the positive potential.
13. The effects of directed drift take place at what rate of speed?
 - a. speed of light
 - b. Speed of sound
 - c. 45,000 feet per second
 - d. 100,000 feet per second
14. Choose the most correct description of the relationship between voltage and current in a circuit.
 - a. Voltage increases as current decreases
 - b. Voltage increases as current increases
 - c. Voltage decreases as current remains steady
15. Convert 350 mA to amperes (A):
 - a. 0.35 A
 - b. 35 A
 - c. 3.50 A
 - d. 3500 A
16. Convert 2.5 A to milliamperes (mA):
 - a. 2.5 mA
 - b. 25 mA
 - c. 250 mA
 - d. 2500 mA

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.

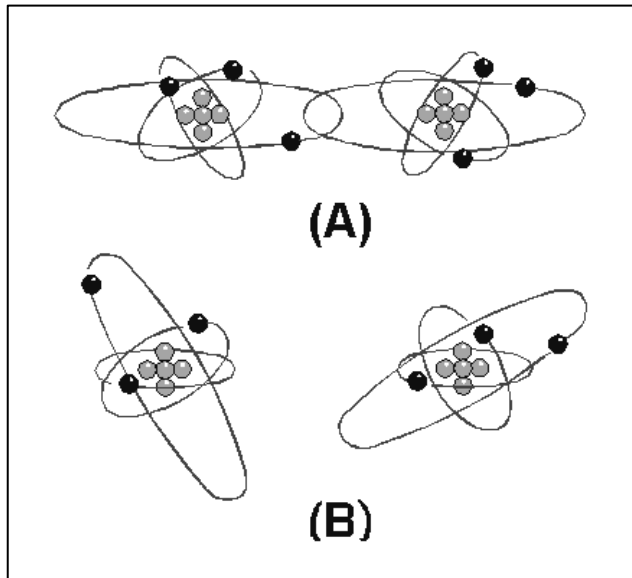


Figure 17: Atomic spacing in conductors.

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 Figure 17 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.

If the atoms of a material are farther apart, as illustrated in Figure 17 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.

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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 18 .

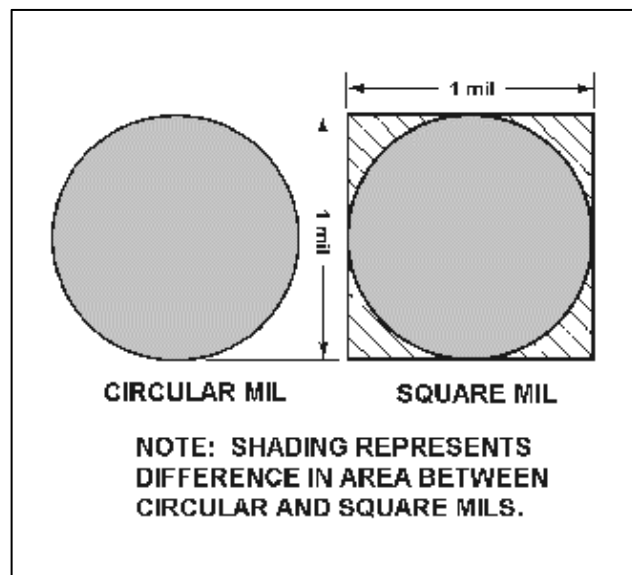


Figure 18: Square and circular mils

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 conductors 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.

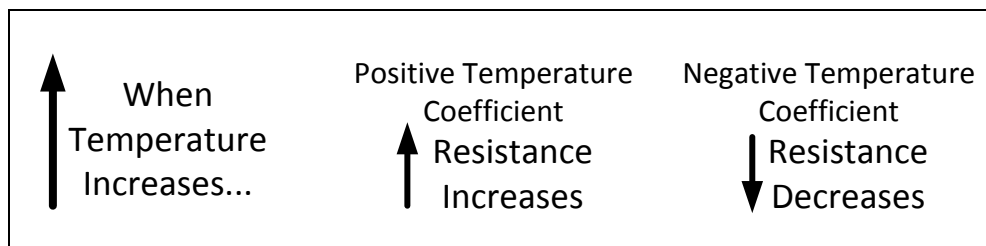


Figure 19: Temperature Coefficients

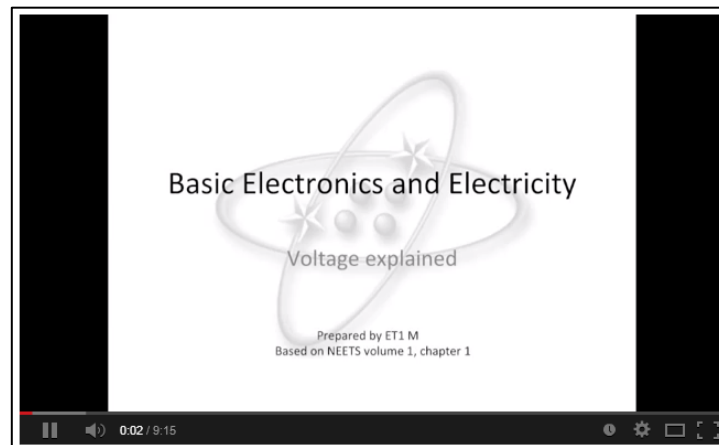
Conductance

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:

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

Equation 1: Resistance and Conductance



Video 2: Basic Electronics and Electricity

<http://www.youtube.com/watch?v=iHwoiQZeAN8>

Knowledge Check

17. True or False. The Greek symbol for omega, Ω , is the symbol for ohms.
18. When weight is a major factor, which conductor would be used:
 - a. Gold
 - b. Copper
 - c. Aluminum
 - d. Silver
19. Select which wire has the least resistance:
 - a. Copper, 1000 circular mils, 6 inches long
 - b. Copper, 2000 circular mils, 11 inches long
20. Which temperature coefficient indicates a material whose resistance increases as temperature increases?
 - a. Positive
 - b. Negative
 - c. Neutral
21. True or False. $R = 1/G$ is the equivalent of $G = 1/R$.

Electrical Safety

Electric Shock Hazard

Electric shock is a jarring, shaking sensation you receive from contact with electricity. You usually feel like you have received a sudden blow. If the voltage and resulting current are sufficiently high, you may become unconscious. Severe burns may appear on your skin at the place of contact; muscular spasms may occur, perhaps causing you to clasp the apparatus or wire which caused the shock and be unable to turn it loose.

The danger of shock from a high-voltage system is well recognized as 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 several factors, including resistance of the body, contact conditions, and the path through the body. 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 milliamperere (0.001 ampere), the shock can be felt.
- At about 10 milliampereres (0.01 ampere), the shock is of sufficient intensity to prevent voluntary control of the muscles.
- At about 100 milliampereres (0.1 ampere) the shock is fatal if it lasts for 1 second or more.

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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 should be treated as potential hazards at all times.

Effects of Electric Current on the Human Body

Before learning safety precautions, you should review of the possible effects of electrical current on the human body. The below table lists some of the probable effects of electrical current on the human body.

AC 60 Hz (mA)	DC (mA)	Effects
0-1	0-4	Perception
1-4	4-15	Surprise
4-21	15-80	Reflex action
21-40	80-160	Muscular inhibition
40-100	160-300	Respiratory failure
Over 100	Over 300	Usually fatal

Table 2: Effects of Current on Human Body

Note in the above table that a current as low as 4 mA can be expected to cause a reflex action in the victim, usually causing the victim to jump away from the wire or component supplying the current. While the current should produce nothing more than a tingle of the skin, the quick action of trying to get away from the source of this irritation could produce other effects (such as broken limbs or even death if a severe enough blow was received at a vital spot by the shock victim).

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It is important to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from a voltage as low as 115 volts or even less. Fatalities caused by human contact with 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. Generally direct current is not considered as dangerous as an equal value of alternating current.

This is evidenced by the fact that reasonably safe "let-go currents" for 60 hertz (alternating current) are 9.0 milliamperes for men and 6.0 milliamperes for women, while the corresponding values for direct current are 62.0 milliamperes for men and 41.0 milliamperes for women. Remember, the above table is a list of probable effects. The actual severity of effects will depend on such things as the physical condition of the work area, the physiological condition and resistance of the body, and the area of the body through which the current flows. Thus, based on the above information, you should consider every voltage as being dangerous.

Precautionary Steps

One 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.

Other signs of possible malfunction:

- 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.

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- Electrical equipment which produces excessive vibrations.

In addition, you should be aware of the following situations:

- **Warning Signs:** These have been posted for your protection and to disregard them is to invite personal injury as well as possible damage to equipment.
- **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 should be done only by authorized persons. Keep your hands off of all equipment for 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. 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 (CO₂) 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 CO₂ 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 CO₂ 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 CO₂ 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:

- Call 911 and/or other emergency responders.
- Remove the victim from electrical contact at once, but DO NOT endanger yourself. You can do this by:
 - Throwing the switch if it is nearby

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- Using a dry stick, rope, belt, coat, blanket, shirt or any other nonconductor of electricity, to drag or push the victim to safety
- Determine whether the victim is breathing. If the victim is not breathing, you must apply artificial ventilation (respiration) without delay, even though the victim may appear to be lifeless. Do not stop artificial respiration until relieved by emergency responders.

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.

Safety Precautions for Preventing Electric Shock

Working safely is the most important thing you can do. Because of their importance, several precautions are listed below. Of course there are more precautions, but these are some you should think about. The keyword here is *think*. Think safety.

- Never work alone. Another person may save your life if you receive an electric shock.
- Never receive an intentional shock.
- Work on energized circuits **ONLY WHEN ABSOLUTELY NECESSARY**.
- Deenergize equipment prior to hooking up or removing test equipment.
- Discharge power capacitors before working on deenergized equipment. Remember, a capacitor is an electrical power storage device.

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- Work with only one hand inside the equipment. Keep the other hand clear of all obstacles that may provide a path, such as a ground, for current to flow.
- Only work on, operate, or adjust equipment if you are authorized.
- Keep loose tools, metal parts, and liquids from above electrical equipment. Never use steel wool or emery cloth on electric and electronic circuits.
- Keep protective closures, fuse panels, and circuit breaker boxes closed unless you are actually working on them.
- Keep a cool head and think about the possible consequences before performing any action. Carelessness is the cause of most accidents. Remember the best technician is NOT necessarily the fastest one, but the one who will be on the job tomorrow.

Shock current path, or Why Birds Don't Get Electrocuted

As we've already learned, electricity requires a complete path (circuit) to continuously flow.

This is why the shock received from static electricity is only a momentary jolt: the flow of electrons is necessarily brief when static charges are equalized between two objects. Shocks of self-limited duration like this are rarely hazardous.

Without two contact points on the body for current to enter and exit, respectively, there is no hazard of shock. This is why birds can safely rest on high-voltage power lines without getting shocked: they make contact with the circuit at only one point (Figure 20).

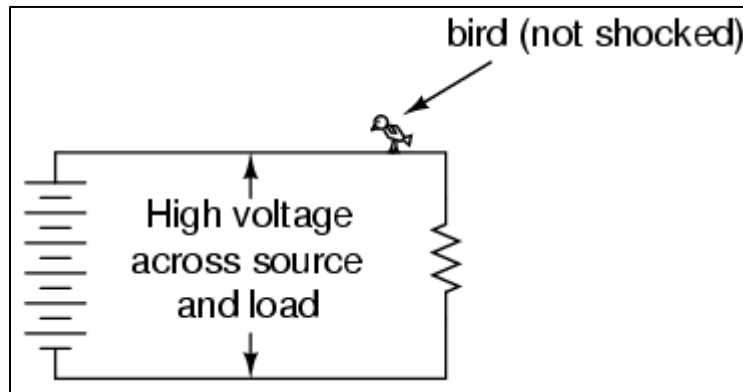


Figure 20: Bird on high voltage.

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In order for electrons to flow through a conductor, there must be a voltage present to motivate them. Voltage is *always relative between two points*. There is no such thing as voltage "on" or "at" a single point in the circuit, so the bird contacting a single point in the above circuit has no voltage applied across its body to establish a current through it. Even though they rest on *two* feet, both feet are touching the same wire, making them *electrically common*. Electrically speaking, both of the bird's feet touch the same point; hence there is no voltage between them to motivate current through the bird's body.

This might lend one to believe that it's impossible to be shocked by electricity by only touching a single wire. Like the birds, if we're sure to touch only one wire at a time, we'll be safe, right? Unfortunately, this is not correct. Unlike birds, people are usually standing on the ground when they contact a "live" wire. Many times, one side of a power system will be intentionally connected to earth ground, and the person touching a single wire is actually making contact between two points in the circuit (the wire and earth ground) (Figure 21):

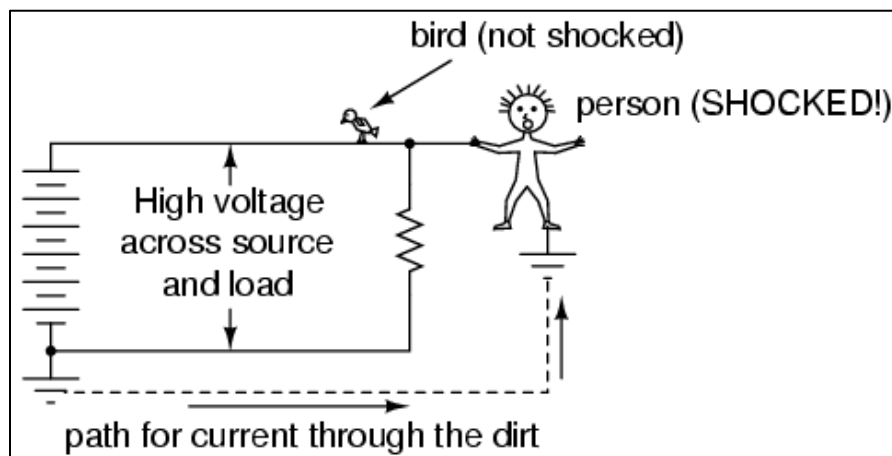


Figure 21: Path for current through the dirt (Earth Ground)

The **ground symbol** is that set of three horizontal bars of decreasing width located at the lower-left of the circuit shown, and also at the foot of the person being shocked. In real life the power system ground consists of some kind of metallic conductor buried deep in the ground for making maximum contact with the earth. That conductor is electrically connected to an

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appropriate connection point on the circuit with thick wire. The victim's ground connection is through their feet, which are touching the earth.

A few questions usually arise at this point in the mind of the student:

- If the presence of a ground point in the circuit provides an easy point of contact for someone to get shocked, why have it in the circuit at all? Wouldn't a ground-less circuit be safer?
- The person getting shocked probably isn't bare-footed. If rubber and fabric are insulating materials, then why aren't their shoes protecting them by preventing a circuit from forming?
- How good of a conductor can dirt be? If you can get shocked by current through the earth, why not use the earth as a conductor in our power circuits?

In answer to the first question, the presence of an intentional "grounding" point in an electric circuit is to ensure that one side of it *is* safe to come in contact with. Note that if our victim in Figure 22 were to touch the bottom side of the resistor, nothing would happen even though their feet would still be contacting ground.

Because the bottom side of the circuit is firmly connected to ground through the grounding point on the lower-left of the circuit, the lower conductor of the circuit is made **electrically common** with earth ground. Since there can be no voltage between electrically common points, there will be no voltage applied across the person contacting the lower wire, and they will not receive a shock. For the same reason, the wire connecting the circuit to the grounding rod/plates is usually left bare (no insulation), so that any metal object it brushes up against will similarly be electrically common with the earth.

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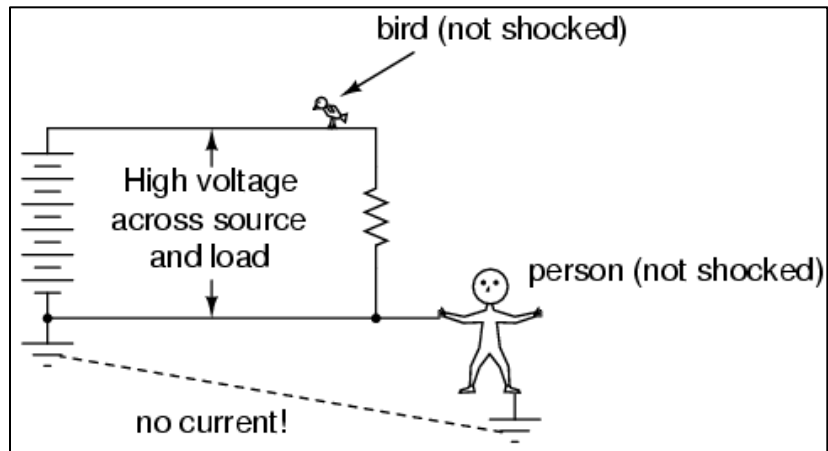


Figure 22: Note where person is touching in regard to ground.

Circuit grounding ensures that at least one point in the circuit will be safe to touch. But what about leaving a circuit completely ungrounded? Wouldn't that make any person touching just a single wire as safe as the bird sitting on just one? Observe what happens in Figure 23 with no ground at all.

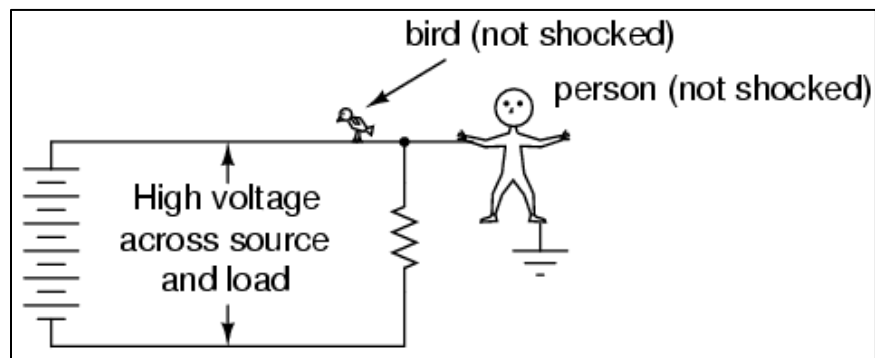


Figure 23: No ground means no complete path.

Despite the fact that the person's feet are still contacting ground, any single point in the circuit should be safe to touch. Since there is no complete path (circuit) formed through the person's body from the bottom side of the voltage source to the top, there is no way for a current to be established through the person. However, this could all change with an accidental ground, such as a tree branch touching a power line and providing connection to earth ground (Figure 24).

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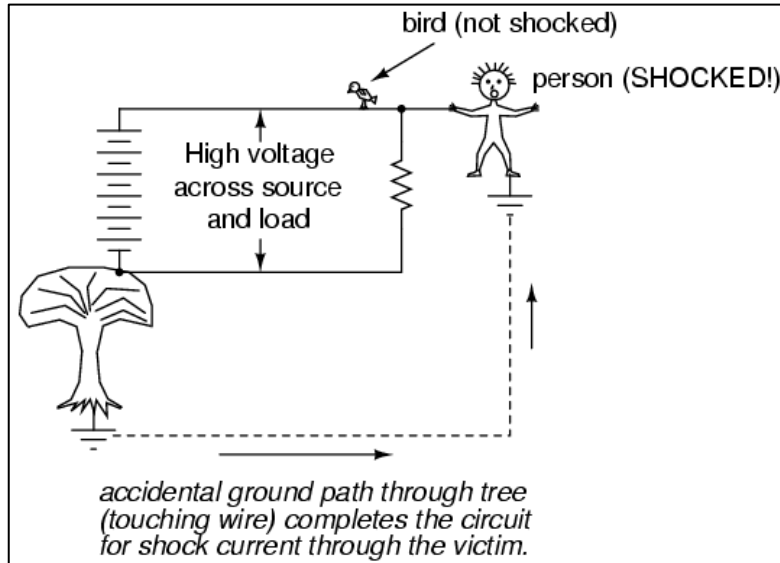


Figure 24: Accidental grounding creates the path.

Such an accidental connection between a power system conductor and the earth (ground) is called a **ground fault**. Ground faults may be caused by many things, including dirt buildup on power line insulators (creating a dirty-water path for current from the conductor to the pole, and to the ground, when it rains), ground water infiltration in buried power line conductors, and birds landing on power lines, bridging the line to the pole with their wings. Given the many causes of ground faults, they tend to be unpredictable. In the case of trees, no one can guarantee *which wire* their branches might touch. If a tree were to brush up against the top wire in the circuit, it would make the top wire safe to touch and the bottom one dangerous -- just the opposite of the previous scenario where the tree contacts the bottom wire, as shown in Figure 25.

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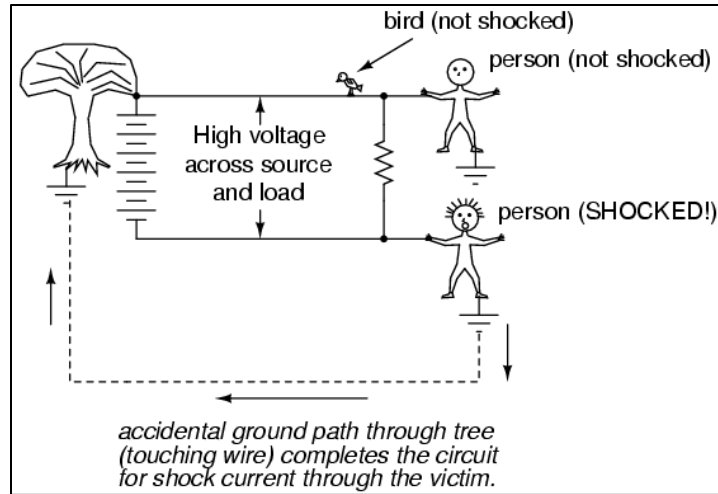


Figure 25: Ground faults

With a tree branch contacting the top wire, that wire becomes the grounded conductor in the circuit, electrically common with earth ground. Therefore, there is no voltage between that wire and ground, but full (high) voltage between the bottom wire and ground. As mentioned previously, tree branches are only one potential source of ground faults in a power system. Consider an ungrounded power system with no trees in contact, but this time with *two* people touching single wires (Figure 26).

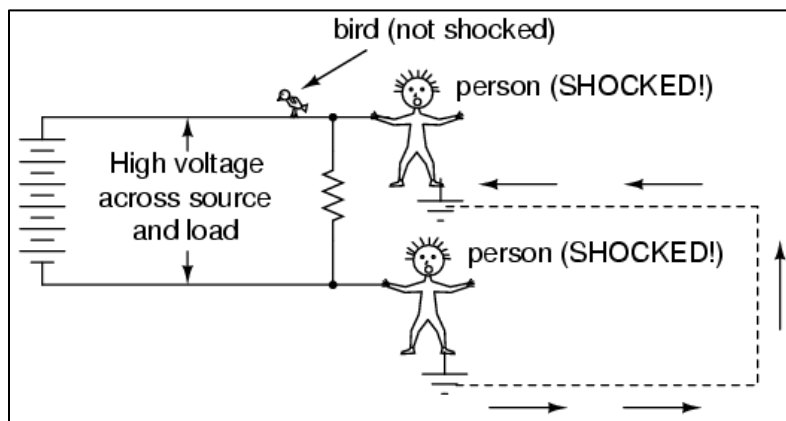


Figure 26: Multiple paths created.

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With each person standing on the ground, contacting different points in the circuit, a path for shock current is made through one person, through the earth, and through the other person. Even though each person thinks they're safe in only touching a single point in the circuit, their combined actions create a deadly scenario. In effect, one person acts as the ground fault which makes it unsafe for the other person. This is exactly why ungrounded power systems are dangerous. The voltage between any point in the circuit and ground (earth) is unpredictable because a ground fault may appear at any point in the circuit at any time. The only character guaranteed to be safe in these scenarios is the bird, which has no connection to earth ground at all! By firmly connecting a designated point in the circuit to earth ground ("grounding" the circuit) safety can at least be assured at that one point. This is more assurance of safety than having no ground connection at all.

In answer to the second question, rubber-soled shoes *do* indeed provide some electrical insulation to help protect someone from conducting shock current through their feet. However, most common shoe designs are not intended to be electrically "safe" as the soles are too thin and not made of the correct substance. Also, any moisture, dirt, or conductive salts from body sweat on the surface of or permeated through the soles of shoes will compromise what little insulating value the shoe had to begin with. There are shoes specifically made for dangerous electrical work, as well as thick rubber mats made to stand on while working on live circuits, but these special pieces of gear must be in absolutely clean, dry condition in order to be effective. Suffice it to say, normal footwear is not enough to guarantee protection against electric shock from a power system.

Research conducted on contact resistance between parts of the human body and a point of contact (such as the ground) shows a wide range of figures (see end of chapter for information on the source of this data):

- Hand or foot contact, insulated with rubber: 20 M Ω typical.
- Foot contact through leather shoe sole (dry): 100 k Ω to 500 k Ω
- Foot contact through leather shoe sole (wet): 5 k Ω to 20 k Ω

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As you can see, not only is rubber a far better insulating material than leather, but the presence of water in a porous substance such as leather *greatly* reduces electrical resistance.

In answer to the third question, dirt is not a very good conductor (at least not when it's dry!). It is too poor of a conductor to support continuous current for powering a load. However, as we will see in the next section, it takes very little current to injure or kill a human being, so even the poor conductivity of dirt is enough to provide a path for deadly current when there is sufficient voltage available, as there usually is in power systems.

Some ground surfaces are better insulators than others. Asphalt, for instance, being oil-based, has a much greater resistance than most forms of dirt or rock. Concrete, on the other hand, tends to have fairly low resistance due to its intrinsic water and electrolyte (conductive chemical) content.

Knowledge Check

22. What can cause a ground fault?
- a. Dirt build-up on power lines
 - b. Ground water
 - c. Tree branches
 - d. All of the above
23. Electric shock can cause:
- a. Burns.
 - b. Muscles to constrict and freeze.
 - c. Death.
 - d. All of the above.
24. When working on electrical equipment, why should you use only one hand?
- a. To allow for greater ease of eating or drinking while working on equipment.
 - b. To ensure that the other hand cannot provide a path for current to flow.
 - c. To allow for waving at your friend when they walk by.
 - d. None of the above.
25. An effect of electric shock hazard can be:
- a. Muscular inhibition or inability to move.
 - b. Death.
 - c. Respiratory failure.
 - d. All of the above.
26. Why don't birds get shocked when they sit on the high-voltage power lines?
- a. Because they have super-insulated feet.
 - b. Because they are extraordinarily lucky.
 - c. Because both of the bird's feet touch the same point of the wire, or are electrically common.
 - d. Because their bones are hollow.

Equipment Safety and Use

Introduction

There are two basic pieces of equipment that will be used throughout this course: the **multimeter** and the **power supply**. The multimeter is a tool for measurement and the power supply is what provides direct current (DC) to the experiments. Multimeters are digital or analog and are available in either bench or handheld models. Power supplies can range from feature rich bench top models to a common household – battery. In this module, you will become familiarized with the various types of multimeters and power supplies and how to safely operate them.

Multimeters

One of the most commonly used tools in an electronics technician’s tool bag is the multimeter. This tool is used to measure voltage, current, resistance, and to check components such as diodes. There are essentially three types of meters that are commonly encountered. These are the bench top digital multimeter, the handheld **digital multimeter (DMM)**, and the handheld analog meter. The bench top DMM provides ease of use and a high level of accuracy. Handheld DMMs offer affordability and portability as well as ease of use. The analog multimeter, while not as common, offers an alternative to digital measurement and is also portable and provides real time measurement.

Digital Multimeter (DMM)

Using an electrical meter safely and efficiently is perhaps the most valuable skill an electronics technician can master, both for the sake of their own personal safety and for proficiency at their trade. It can be daunting at first to use a meter, knowing that you are connecting it to live circuits that may harbor life-threatening levels of voltage and current. This

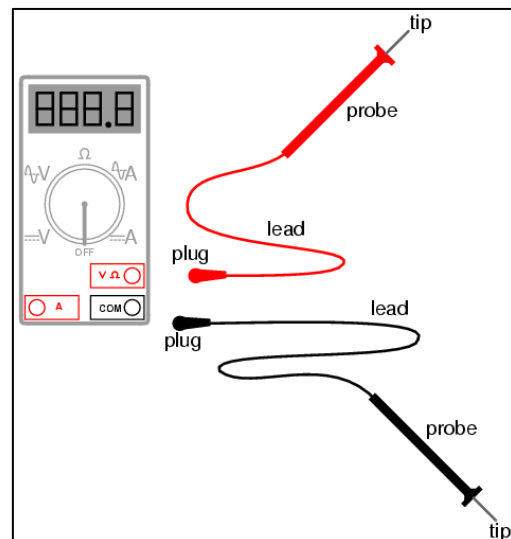


Figure 27: Digital Multimeter

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concern is not unfounded, and it is always best to proceed cautiously when using meters. Even for experienced technicians, it is carelessness, more than any other factor, which causes electrical accidents.

The digital multimeter, or the DMM, comes in both handheld and bench versions. They have the ability to measure resistance, voltage, and current. The bench meter is slightly different, having pushbutton selections rather than a knob, and having a few more features, but overall bench and hand held meters have the same functions and safety considerations.

The basic concepts of the handheld and bench DMM are similar. There is an LED/LCD screen to show the measurement, and a method for choosing what is being measured. On the bench models, there are push buttons for DC Volts, DC Amps, AC Volts, AC Amps, and others. On the handhelds, there is a rotary selector switch with different measurement positions it can be set in: two "V" settings, two "A" settings, and one setting in the middle with an ohms (Ω) symbol on it representing resistance.

Of the two "V" settings and two "A" settings, you will notice that each pair is divided into unique markers with either a pair of horizontal lines (one solid, one dashed), or a dashed line with a squiggly curve over it. The parallel lines represent "DC" while the squiggly curve represents "AC." The "V" stands for "voltage" while the "A" stands for "amperage" (current). The meter uses different techniques, internally, to measure DC than it uses to measure AC, and so it requires the user to select which type of voltage (V) or current (A) is to be measured. Although we have not discussed alternating current (AC) in any technical detail, this distinction in meter settings is an important one to bear in mind.

It is important to set the proper range. If too high, the meter will display "OL," or sometimes "0." If too low, the meter will display a very small number (0.001) or 0.000. If it is auto-ranging (like the bench model), it will adjust where the decimal point is.

There are three different sockets on the multimeter face into which we can plug **test leads**. Test leads are nothing more than specially prepared wires used to connect the meter to the circuit under test. The wires are coated in a color-coded (either black or red) flexible insulation

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to prevent the user's hands from contacting the bare conductors, and the tips of the probes are sharp, stiff pieces of wire.

The black test lead *always* plugs into the black socket on the multimeter: the one marked "COM" for "common." The red test lead plugs into either the red socket marked for voltage and resistance, or the red socket marked for current, depending on which quantity you intend to measure with the multimeter.

Measuring DC Voltage

To see how this works, let us look at a couple of examples showing the meter in use. First, we will set the meter to measure DC voltage from a battery. Figure 28 shows the two test leads plugged into the appropriate sockets on the meter for voltage, and the selector switch has been set for DC "V."

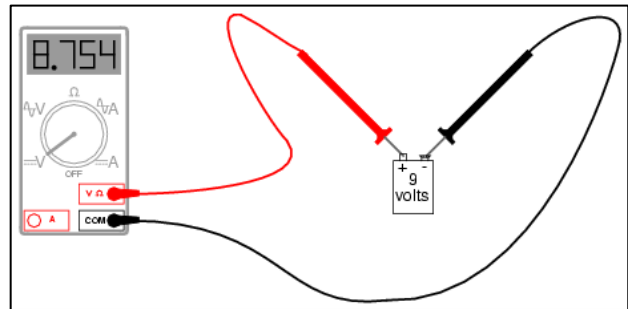


Figure 28: Measuring DC Voltage

Measuring AC Voltage

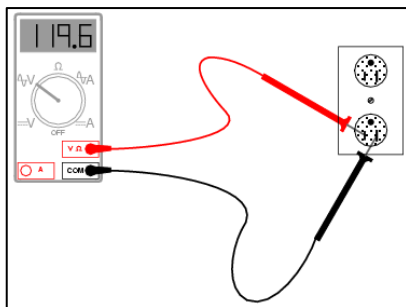


Figure 29: Correct!

For measuring AC, only difference in the setup of the meter is the placement of the selector switch (Figure 29). Because voltage is being measured, the test leads will remain plugged in the same sockets. In both of these examples, it is ***imperative*** that you not let the probe tips come in contact with one another while they are both in contact with their respective points on the circuit. If this happens, a short-circuit

will be formed, creating a spark and perhaps even a ball of flame if the voltage source is capable of supplying enough current (Figure 30).

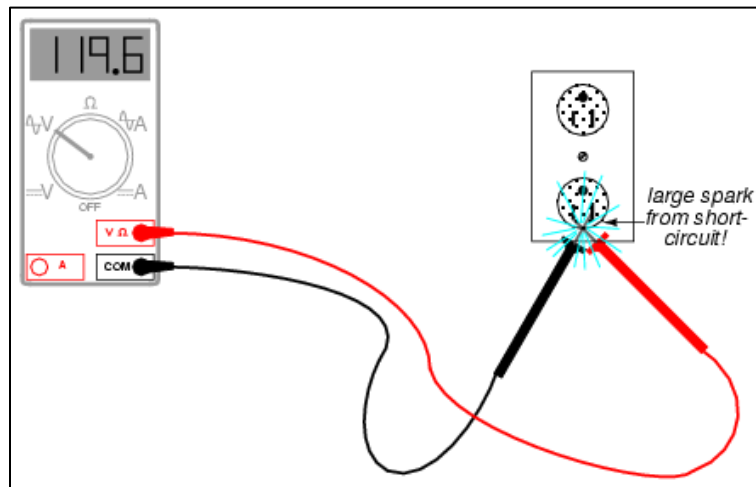


Figure 30: Short Circuit!

Safety

Considerations of Measuring Voltage

Voltage measurement is perhaps the most common function of a multimeter. Voltage is the primary measurement taken for safety purposes and needs to be understood by the operator. **Because voltage is relative between two points, the meter *must* be firmly connected to two points in a circuit before it will provide a reliable measurement.** To prevent possible shock, use test leads with a spring clip or other gripping device to connect to the circuit. This ensures that at least one hand is kept free and helps to prevent a path to ground through your body.

Measuring Resistance

Using a multimeter to check for resistance is a fairly simple task. The test leads will be kept plugged into the same sockets as for the voltage checks, but the selector switch will need to be turned until it points to the resistance (Ω) symbol. After touching the probes across the device whose resistance is to be measured, the meter should properly display the resistance in ohms, as shown in Figure 31.

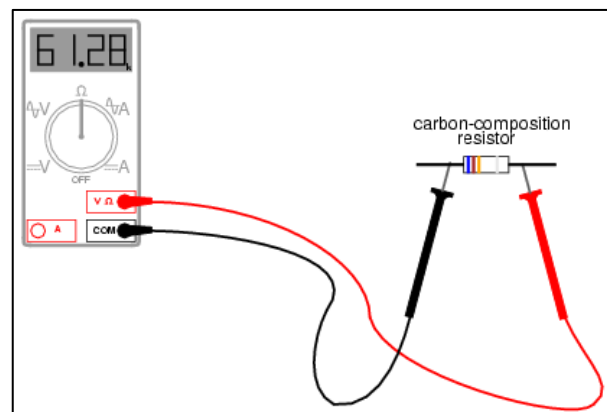


Figure 31: Measuring Resistance

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Measuring resistance must be done on **de-energized** components. When the meter is in "resistance" mode, it uses a small internal battery to generate a tiny current through the component to be measured. By sensing how difficult it is to move this current through the component, the resistance of that component can be determined and displayed. If there is any additional source of voltage in the meter-lead-component-lead-meter loop to either aid or oppose the resistance-measuring current produced by the meter, faulty readings will result. In a worse case situation, the meter may even be damaged by the external voltage.

Measuring Continuity

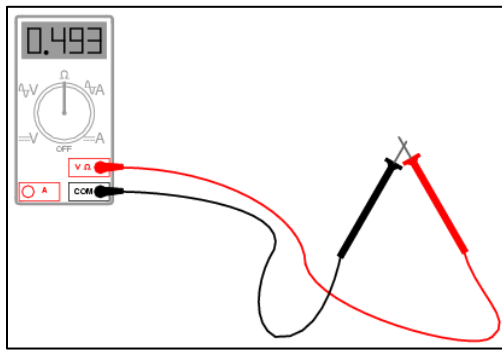


Figure 32: Measuring Continuity

The resistance mode of a multimeter is also useful in determining wire **continuity**. Continuity is the opposite of resistance, therefore, when there is a good, solid connection between the probe tips, simulated by touching them together as shown in Figure 32, the meter shows almost zero Ω . If the test leads had no resistance in them, it would read exactly zero, however, since there is resistance in the wires, the meter will show a very small number.

If the leads are not in contact with each other, or touching opposite ends of a broken wire, the meter will indicate infinite resistance, usually by displaying dashed lines or the abbreviation "OL" which stands for "open loop," as shown in Figure 33.

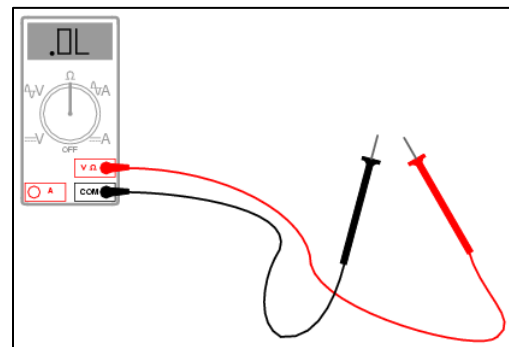
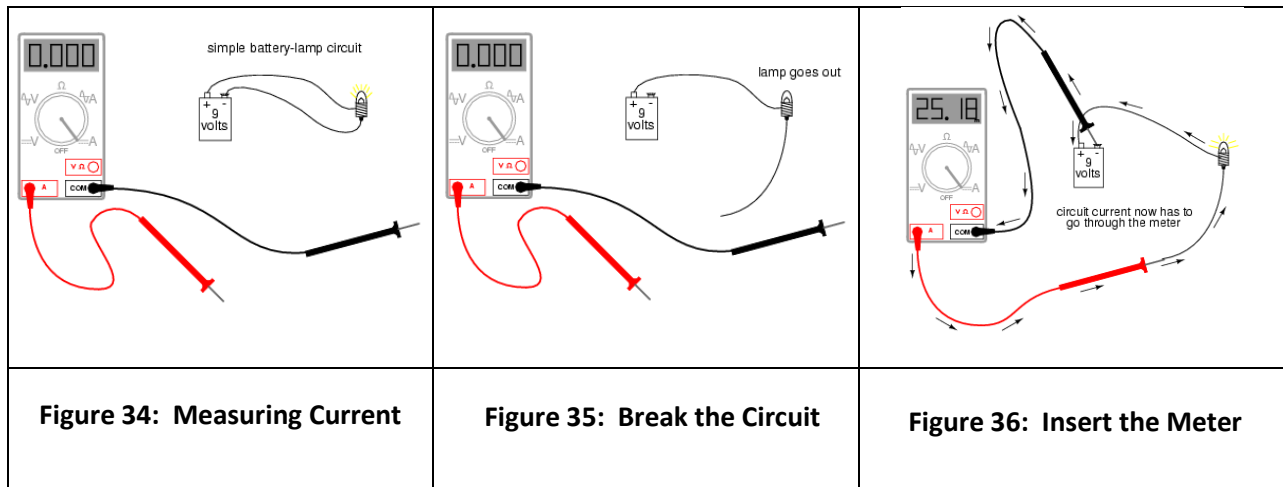


Figure 33: Open Loop

Measurement of Current

By far the most hazardous and complex application of the multimeter is in the measurement of current. The reason for this is quite simple: in order for the meter to measure current, the current to be measured must be forced to go *through* the meter. This means that the meter must be made part of the current path of the circuit rather than just be connected off to the side somewhere as is the case when measuring voltage. This configuration is known as “being in series.” In order to make the meter part of the current path of the circuit, the original circuit must be “broken” and the meter connected across the two points of the open break. To set the meter up for this, the selector switch must point to either AC or DC “A” and the red test lead must be plugged in the red socket marked “A”. Figure 34 illustrates a meter all ready to measure current and a circuit to be tested. Next, the circuit is broken in preparation for the meter to be connected (Figure 35).

Finally, the meter is inserted in-line with the circuit by connecting the two probe tips to the broken ends of the circuit, the black probe to the negative (-) terminal of the 9-volt battery and the red probe to the loose wire end leading to the lamp (Figure 36).



Safety Consideration When Measuring Current


A potential hazard of using a multimeter in its *current-measuring* ("ammeter") mode is failure to put it into a voltage-measuring configuration before measuring voltage. The reasons for this

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are specific to ammeter design and operation. When measuring circuit current by placing the meter directly in the path of current, it is best to have the meter offer little or no resistance against the flow of electrons. Otherwise, any additional resistance offered by the meter would impede the electron flow and alter the circuits operation. Thus, the multimeter is designed to have practically zero ohms of resistance between the test probe tips when the red probe has been plugged into the red "A" (current-measuring) socket. In the voltage-measuring mode (red lead plugged into the red "V" socket), there are many mega-ohms of resistance between the test probe tips, because voltmeters are designed to have close to infinite resistance (so that they *do not* draw any appreciable current from the circuit under test).

When switching a multimeter from current- to voltage-measuring mode, it is easy to spin the selector switch from the "A" to the "V" position and forget to switch the position of the red test lead plug from "A" to "V." The result -- if the meter is then connected across a source of substantial voltage -- will cause a short-circuit through the meter!

To help prevent this, some multimeters have a warning feature by which they beep if ever there's a lead plugged in the "A" socket and the selector switch is set to "V." While this can help avert damage, most meters have fuses to protect them from damage.

 <p>For this example, a digital multimeter is used, which will be connected to a simple circuit.</p>	 <p>USING A DIGITAL MULTIMETER TO MEASURE VOLTAGE, RESISTANCE AND CURRENT</p>
<p>Video 3: How to use a DMM I http://www.youtube.com/watch?v=646CbvaEtww</p>	<p>Video 4: How to use a DMM II http://www.youtube.com/watch?v=sKuPd3X <u>YwuA</u></p>

Fuses

Meters of all types are very likely to contain **fuses**. As you start to use meters, you will find that fuses will blow. Mistakes made while measuring current are common for new students and the fuse protects the meter from being ruined. When the fuse has blown, the meter will still operate, though you may get erroneous readings, particularly for current. If you get voltage and resistance measurements that are close to expected, but current readings are extremely low, suspect a blown fuse.

Checking a Fuse

You can visually inspect a fuse to see if the wire inside is broken. However, it is difficult to tell for certain. Because the wire provides continuity through the fuse, you can use an ohmmeter to check for continuity. Most DMM have a setting that looks like a speaker, this is the continuity checker. It provides an audible tone if the fuse is still functional, or will indicate “OL” or other visual indicator for no continuity.

A multimeter can also be used to check its own current fuse by setting the selector switch to the resistance position and creating a connection between the two red sockets like as shown in Figure 37:

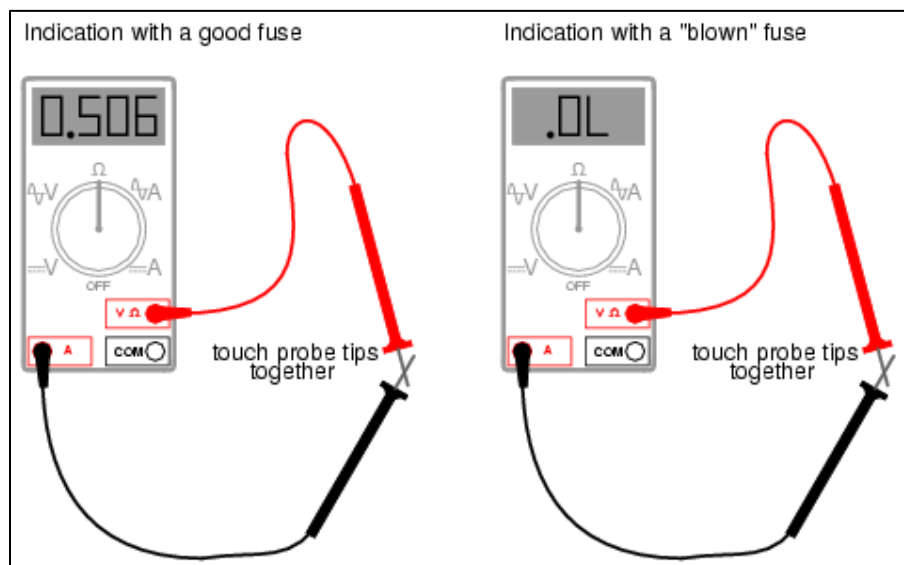


Figure 37: Checking a Meter's Fuse

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A good fuse will indicate very little resistance while a blown fuse will always show "OL," or whatever indication that model of multimeter uses to indicate no continuity. The actual number of ohms displayed for a good fuse is of little consequence, so long as it is an arbitrarily low figure.

Replacement of Fuses

After an open fuse is found and the trouble that caused the fuse to open has been corrected, the fuse must be replaced. Before you replace the fuse, you must be certain the replacement fuse is the proper type and fits correctly.

To be certain a fuse is the proper type; check the technical manual for the equipment. The parts list will show you the proper fuse identification for a replacement fuse. If you cannot obtain a direct replacement, use the following guidelines:

- Never use a fuse with a higher current rating, a lower voltage rating, or a slower time delay rating than the specified fuse.
- The best substitution fuse is a fuse with the same current and time delay ratings and a higher voltage rating.
- If a lower current rating or a faster time delay rating is used, the fuse may open under normal circuit conditions.
- Substitute fuses must have the same style (physical dimensions) as the specified fuse.

Analog Multimeter

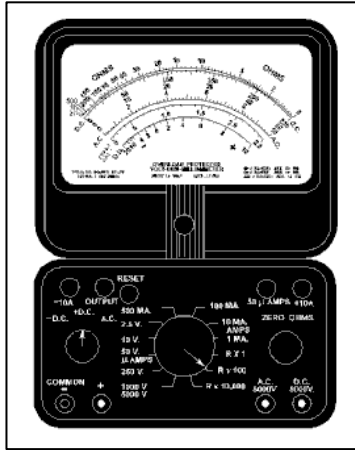


Figure 38: Analog Meter

Other meters you may encounter are **VOM** (Volts-Ohm-Milliammeter) and **VTVM** (Vacuum Tube Voltage Meter). In the case of the VTVM, it is unlikely that you will encounter one, but the term is still used. The VOM is not as common, but is still used in some applications. This is an analog device that measures Resistance, Voltage, and Current using linear and nonlinear scales.

There are several advantages in using the Simpson 260:

instantaneous results and portability. Instantaneous because as the technician makes adjustments, the needle will move without the delay, albeit small, that exists in the digital multimeter due to the process of analog to digital conversion. Analog multimeters are relatively small and can be carried easily. However, there are disadvantages. They lack the precision and accuracy of a digital multimeter and are susceptible to damage caused by environment factors and human errors. A major disadvantage is parallax error. **Parallax error** is defined as the apparent displacement of the position of an object because of the difference between two points of view. In the case of meters, this means the position of a meter's pointer will appear to be at different positions on the scale depending on the angle from which the meter is viewed.

Analog and digital multimeters differ slightly when measuring voltage and current. However, when measuring resistance, there are significant differences. Measuring resistances with the analog multimeter requires making the appropriate range setting using a multiplication factor. Always set the meter to a higher range than anticipated, then touch the leads together and zero the meter using the ZERO dial. This must be done each time you change the range. It is also important to understand that for very small or very large resistances, you may not be able to get an accurate reading. In addition, when measuring very small resistance, it is possible that the meter will load the resistance. This means that the small voltage used by the meter when measuring resistance can negatively affect the component being measured.

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In comparison, the handheld digital multimeter has a dial with settings at 200 Ω , 2,000 Ω , 20,000 Ω , 200,000 Ω , 2,000,000 Ω , and 20,000,000 Ω . The bench top digital multimeter has auto ranging, which simplifies measurement readings as it automatically adjusts to the amount of resistance being measured. It also has internal protections to prevent the adverse effects of taking measurements on the wrong setting or using the incorrect range. Below is a chart comparing the range settings for each type of meter. You can see that they are essentially the same, but the DMM settings are more intuitive than the multiplication factor used by the analog meters.

Ohmmeter Settings – Analog Meter	
Multiplication Factor	Range of Resistance
R x 1	0 - 200 Ω
R x 100	200 – 20,000 Ω
R x 1000	Over 20,000 Ω

Table 3: Multiplication Factors for Analog Meter

Ohmmeter Settings – Handheld Digital Multimeter	
Range Setting	Range of Resistance
200	0 - 200 Ω
2,000	200 – 2,000 Ω
20,000	2,000 - 20,000 Ω
200,000	20,000 – 200,000 Ω
2,000,000	200,000 – 2,000,000 Ω
20,000,000	Over 2,000,000 Ω

Table 4: DMM Resistance Range Settings

Protecting Yourself

Measuring Current

When you use an ammeter, certain precautions must be observed to prevent injury to yourself or others and to prevent damage to the ammeter or the equipment on which you are working. The following list contains the **MINIMUM** safety precautions to observe when using an ammeter.

- Ammeters must always be connected in series with the circuit under test. That means they must be inserted into the circuit at the point being measured.
- Always start with the highest range of an ammeter.
- Deenergize and discharge the circuit completely before you connect or disconnect the ammeter.
- In dc ammeters, observe the proper circuit polarity to prevent the meter from being damaged.
- Never use a dc ammeter to measure ac.
- Observe the general safety precautions of electrical and electronic devices.

Measuring Voltage

Just as with ammeters, voltmeters require safety precautions to prevent injury to personnel and damage to the voltmeter or equipment. The following is a list of the **MINIMUM** safety precautions for using a voltmeter.

- Always connect voltmeters in parallel.
- Always start with the highest range of a voltmeter.
- Deenergize and discharge the circuit completely before connecting or disconnecting the voltmeter.
- In dc voltmeters, observe the proper circuit polarity to prevent damage to the meter.
- Never use a dc voltmeter to measure ac voltage.
- Observe the general safety precautions of electrical and electronic devices.

Measuring Resistance

The following safety precautions and operating procedures for ohmmeters are the **MINIMUM** necessary to prevent injury and damage.

- Be certain the circuit is deenergized and discharged before connecting an ohmmeter.
- Do not apply power to a circuit while measuring resistance.
- When you are finished using an ohmmeter, switch it to the OFF position if one is provided and remove the leads from the meter.
- Always adjust the ohmmeter for zero (or ∞ in shunt ohmmeter) after you change ranges before making the resistance measurement. (Analog)

Protecting the Equipment

The electrical measuring instruments included in test equipment are delicately constructed and require certain handling precautions to prevent damage and to ensure accurate readings.

While it is possible to find very inexpensive handheld DMMs, bench top models and higher quality handheld models can be very expensive. Analog meters can also be expensive.

To prevent damage to electrical measuring instruments, you should observe the precautions relating to three hazards: mechanical shock, exposure to magnetic fields, and excessive current flow.

Mechanical Shock

Instruments contain permanent magnets, meters, and other components that are sensitive to shock. Heavy vibrations or severe shock can cause these instruments to lose their calibration accuracy.

Exposure to Strong Magnetic Fields

Strong magnetic fields may permanently impair the accuracy of a test instrument. These fields may impress permanent magnetic effects on permanent magnets, moving-coil instruments, iron parts of moving-iron instruments, or in the magnetic materials used to shield instruments.

Excessive Current Flow

This includes various precautions, depending on the type of instrument. When in doubt, use the maximum range scale on the first measurement and shift to lower range scales only after you verify that the reading can be made on a lower range. If possible, connections should be made while the circuit is de-energized. All connections should be checked to ensure that the instrument would not be overloaded before the circuit is reenergized.

Other Instrument Precautions

Precautions to be observed to prevent instrument damage include the following:

- Never leave an analog instrument connected with its pointer off-scale or deflected in the wrong direction.
- Never attempt to measure the internal resistance of a meter movement with an ohmmeter since the movement may be damaged by the current output from the ohmmeter.
- Before measuring resistance, always discharge any capacitors in the circuit to be tested. Note and record any points not having bleeder resistors or discharge paths for capacitors.
- Always disconnect voltmeters from field generating or other highly inductive circuits before you open the circuit.

Power Supplies

A direct current (DC) power supply can be either a variable triple output bench model or a battery. For most modules, a 9 V battery will be a sufficient power source for your experiments. Be aware that some functionality will be lost when using a battery and that variable DC power supplies can be purchased at low cost.

Bench Power Supplies

A bench power supply normally provides 0 – 24 V of DC voltage. For safety reasons, the amount of current is usually limited to not more than 1 Amp. As you have read, it is the current

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that is of greater concern. In future modules, you will learn that even with a steady low voltage, as you incorporate resistance into your circuits, the amount of current will vary.

Triple Output DC Power Supply

The triple output DC power supply is commonly found in electronics labs due to its ease of use, relative safety and multiple outputs. Shown below is a typical triple output power supply. The triple output is due to it having two variable outputs and one fixed output. The variable outputs typically supply 0-30 V of DC with the current limited to help protect equipment, components, and especially, people. As you will learn in later modules, voltage, current, and resistance form a relationship called “Ohm’s Law.” In short, when one of those changes, the other two will either change directly or inversely proportionate in response. For working with digital electronics and other applications requiring 5 V, there is an output with fixed voltage and current settings.

The Triple Output Power Supply as shown in Figure 39 is fairly common. Note a box is drawn around the set of controls for one of the variable outputs. The C.V. and C.C indicator lights let you know whether current or voltage is being held constant. For our purposes, we want a constant voltage. The output also has three input jacks, one labeled “-,” one labeled “+,” and one labeled “GND.” When setting up your circuit, you will use the “-“and “+.” In future modules, you will need to insert a ground point into your circuit. At that time, you will use the “GND” input.

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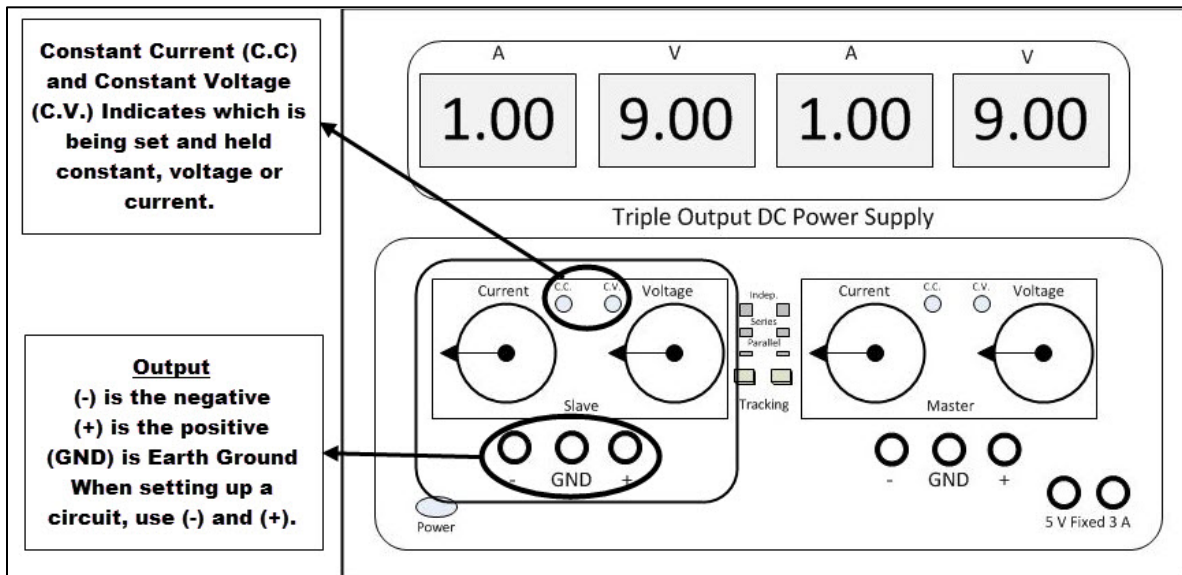


Figure 39: Standard Triple Output DC Power Supply

Notice that each of the two variable outputs is labeled Master and Slave. In the center, there are a set of buttons which allow you to set whether the two outputs operate in series (additive), in parallel (supply the same current/voltage), or independently. For most purposes, the power supply needs to be set as independent.

Safety Considerations

Normal lab safety procedures should always be observed when using a power supply. Ensure that the settings for current and voltage are both set to zero before connecting a circuit and turning on the power. If you are working with a sensitive circuit, it could be damaged by excessive current or voltage.

Batteries

Batteries are an alternative to a DC Power Supply as described above. Regular batteries (AAA, AA, C, and D) are 1.5 V. For most DC experiments, however, a single regular 9 V battery would be sufficient. They are very simple to use and relatively safe as well.

Safety Considerations

When using a battery, it is important to inspect it to ensure there is no leakage or corrosion. Also, because they are a finite source, it is necessary to test them with a voltmeter to ensure that you are still getting the nominal voltage. Use a DMM to measure the voltage. A battery with less than 9V will not provide expected results.

Knowledge Check

27. When measuring AC voltage, if the test leads come into contact with one another while measuring the live circuit, there will be:
- a. an open circuit
 - b. a short circuit (CORRECT)
 - c. a long circuit
 - d. nothing
28. The most hazardous and complex application of the digital multimeter (DMM) is the measurement of
- a. Current (CORRECT)
 - b. Resistance
 - c. Voltage
 - d. Power
29. When measuring current,
- a. connect the ammeter in line, or in series, with the circuit being tested (CORRECT)
 - b. always start with the highest range of the ammeter
 - c. De-energize or discharge the circuit completely before connecting the ammeter
 - d. All of the Above (CORRECT)
30. When measuring voltage
- a. Always connect the voltmeter across, or in parallel with, the component being tested
 - b. always start with the highest range on the voltmeter
 - c. never use the dc voltage setting to measure ac voltage
 - d. all of the above (CORRECT)
31. When measuring resistance
- a. De-energize or discharge the circuit completely before connecting the ohmmeter
 - b. Do not apply power when measuring resistance.
 - c. Set the dial to “Resistance”
 - d. All of the above (CORRECT)

Lab Skills

Reading a Schematic

Building a circuit requires a schematic. A **schematic** is a kind of road map for how the circuit will work. It traces the path that the electrons will flow through the circuit. In the early labs, schematics will be simple. As you progress, the circuits will become more complicated and the configuration of the schematics will change as well.

Schematic Symbols and Terms






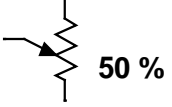

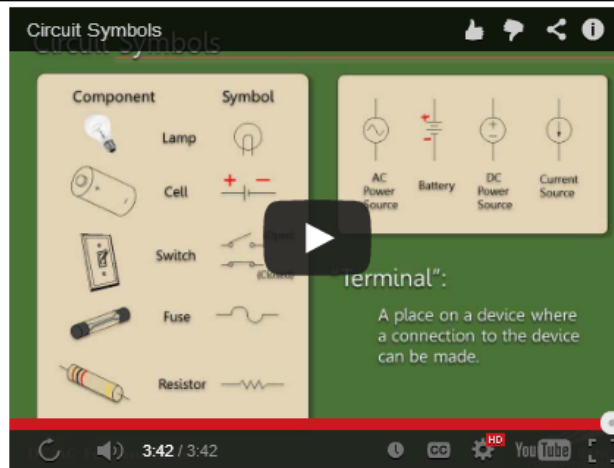
<p>+ (positive)</p>  <p>- (negative)</p>	Voltage	This symbol is used in this course to indicate a DC voltage source such as a DC Power Supply or a battery. The voltage level will be indicated in units of volts, V. The longer lines are positive and the shorter lines are negative.
	Ground	This symbol indicates ground.
	Resistor	This is the symbol for resistors. The resistance will be indicated in units of ohms, Ω .
	Lamp	Many of the labs use an indicator lamp.
	LED (Light Emitting Diode)	LEDs are used in the labs to provide a visual indication of electron flow. They will be covered more in depth in later courses.
	Potentiometer	A potentiometer is a variable resistor. The “pot’s” total resistive value will be indicated in ohms. In this image, the percentage of that value is indicated. 50% indicates that only half of the resistance is being used.
	Wire	Straight lines connect each component.

Table 5: Common Schematic Symbols

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Video 5: Circuit Symbols

(<http://contentbuilder.merlot.org/toolkit/html/snapshot.php?id=72010076113055>)

Basic Bread Boarding

Throughout this course, you will be building and demonstrating circuits. To do this, you will use a bread board. This simple tool allows you to set up circuits for your experiments, take measurements, then do it all again for the next experiment. They are simple to use, but do take some practice. If you are new to bread boarding, the easiest way to ensure that mistakes are not made is to construct your circuit on the bread board look as much like the drawn circuit as possible.

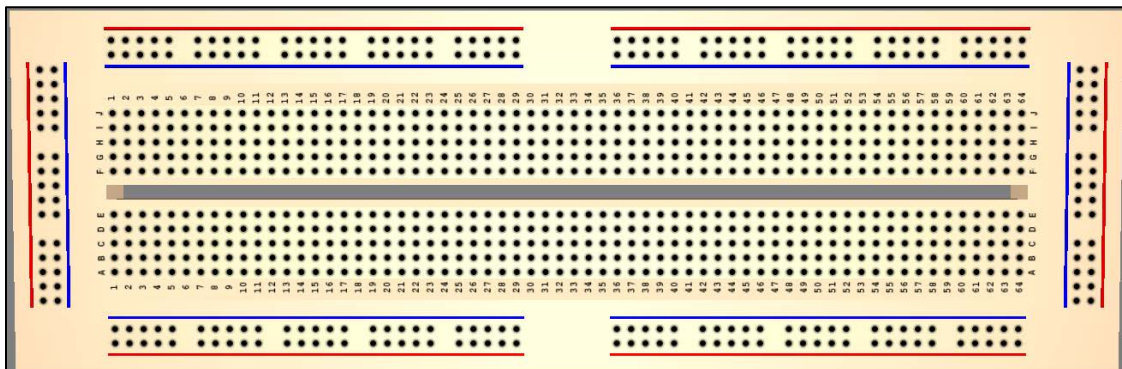


Figure 40: Basic bread board.

The Bread Board

As shown in Figure 40, the **bread board** is basically just a convenient place to insert wires and components. Without it, you would need to figure out a way to hold all the components and wires together while designing a circuit. When you needed to make a change, you would have to disconnect all the connections, change the part, and then connect it all together again. With a bread board, you merely lift out the component you wish to change and insert a new one. If wires must be moved, you simply unplug the wire and move it to the new location.

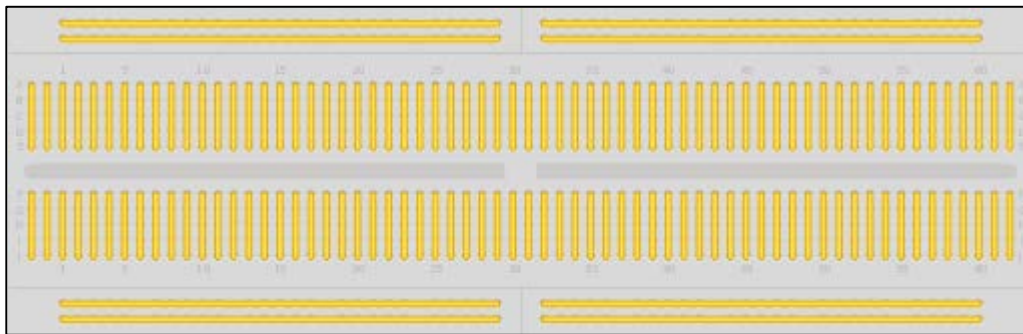


Figure 41: Inside the breadboard

If you could see inside the breadboard, it would look like the image in Figure 41. This image shows how the holes on the breadboard are connected on the inside. Any hole that lies on the same line (or wire) are said to be electrically common. Any connection along that same set of holes is the same connection. The areas that are outlined with red and blue stripes are bus lines. The area in the center is where circuits are built.

Bus Lines

Bus lines are areas from which connections can be made anywhere along the line. They are not required for use, but do allow for flexibility and convenience. On the bread board, locate the sections with blue and red lines. These indicate the buses. The red is normally used for positive (voltage) and the black for negative (or ground). Once again, this is not a requirement, but it is

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generally expected and accepted that red represents positive or “hot” and black or dark blue represents negative.

In the center area of the bread board, there are numbered rows and lettered columns with a channel that goes down the middle of each side. The center channel isolates one set of rows and columns from the next and is used with integrated circuit (IC) chips. When circuits are built, it is this area that is used.

Wires & Jumpers

Copper wire creates the path that connects components together in an electric circuit. In later modules, you will learn more details about wire, but for now, it is important to have only a basic understanding. Standard wire sizes are measured in **AWG** (American Wire Gage). Unlike most measurements, the larger the gage, the smaller the wire.

The wire used for bread boarding is single strand 22 AWG, or 22 gage. Most of the components have pins or legs of the same or smaller size. For larger wattage resistors, the legs will be a bit larger. If you are having difficulty inserting a wire or component into the holes on a breadboard, please stop and ask for assistance. Forcing the wire or component into the breadboard will damage it.

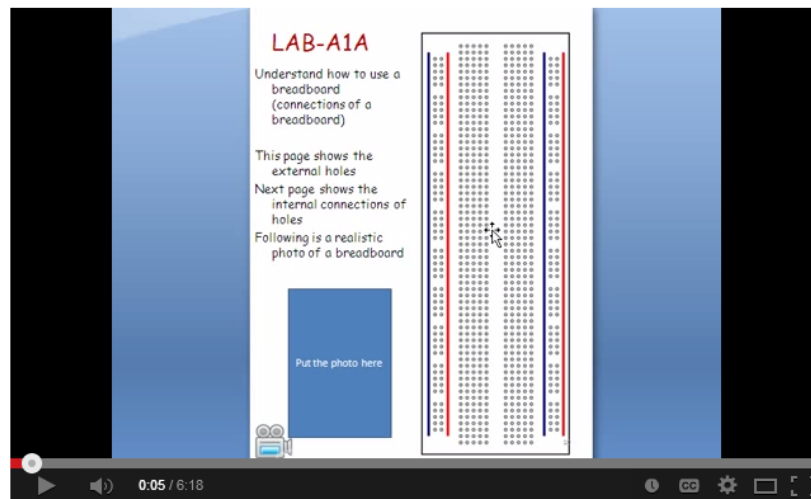
Because the bread boarding wire is single strand, it is not as resistant to damage by bending and twisting as stranded wire. The test leads and cables used for the power supplies are made of stranded wire and as such are much better suited to being manipulated. If you start to experience trouble with a bread board wire, it could be that it has been bent and reused one time too many. As you progress through the program, you will find that you will collect a collection of color coded jumpers. Inspect them occasionally for damage such as crimps, bends, and missing insulation. Missing insulation can become a shock hazard. Dispose of and replace any wire that has insulation missing and have exposed copper.

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Wire in the lab will be called by several different names: jumper, wire, cable. It also comes in a variety of color. Color coding wire makes complex circuitry easier to follow. Some basic color coding is red for positive and black for negative or ground.

Preparing wire for use in the breadboard is simple and involves the use of wire strippers:

- Cut off the amount of wire needed
- Using the wire strippers, insert one of the wires into the slot labeled “22.” You only need about 1/8” of bare wire. While squeezing the handles, pull the long end of the wire away from the strippers
- Repeat on the other end.
- Dispose of the insulating material in the trash.

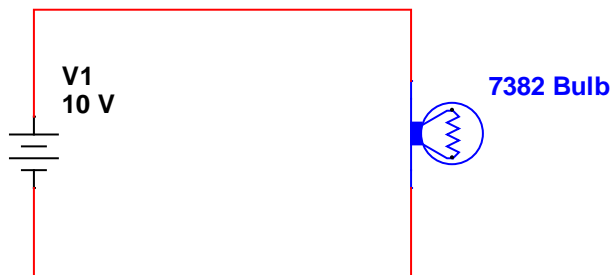


Electricity Lab 1: Building a Simple Circuit

Components & Equipment Needed

- Bread Board
- Wire (22 AWG)
- DC Power Supply
- DMM
- 7382 Bulb

Circuit Diagram



Circuit 1: Circuit Diagram for Electricity Lab 1

Additional Instructions

These instructions are the standard requirements for the Electronics Program:

- When making measurements, always include the appropriate symbol for the unit of measurement (V, I, or Ω).
- Measurements should be taken to the 3rd place after the decimal.
- Leading zeroes are required for measurements less than one.
- Use engineering notation. For review see Grob's Basic Electronics, Introductory Chapter. For example, if you get the result "40421.01289 Ω ," record your answer as "40.013 k Ω ." Or "0.00124963 A," write this as "0.001 A" or "1 mA."

Procedure

Step 1: Preparing the Breadboard

- Connect the voltage and ground terminals to the breadboard by unscrewing the binding post nuts until you can see a small hole in the shaft.
- Using about 3" of 22 AWG wire that has been stripped of about ¼" of insulator at each end, insert one end into the hole and tighten down the nut. Insert the other end into the appropriate bus line. Keeping wires color-coded can simplify things.
- Use a small piece of wire (about 1") to make a jumper. Strip off both ends about ¼". You will need two of these: one for voltage and one for ground.
- Insert one of the jumpers into the voltage (red) bus and the other end into the working area of the bread board.

Step 2: Building the Circuit

- Insert the 7382 bulb so that one pin is in the same row as the jumper from the voltage bus and the other is in the next column.
- Insert the other jumper into the same row as the second pin of the 7382 bulb and the other end into the ground (blue) bus.

Step 3: Setting Up the Power Supply

- If you are using a variable DC Power Supply, follow the manufacturer directions for your particular model to set it for an output of 10 V. A typical Triple Output DC Power Supply as shown below is referenced in the following instructions.
- Make sure the knobs on the power supply are turned all the way to the left (zero) and that it is set to "Independent." With this setting, you can use either side of the power supply.
- Turn on the power supply and adjust the voltage knob until the CV (green) light clicks off and the CC (red) light clicks on. Watching the voltage reading on the LED screen, continue adjusting knobs until it reads 10.0 V. (C.V. means "Constant Voltage," C.C. means "Constant Current.")
- Turn off the power supply

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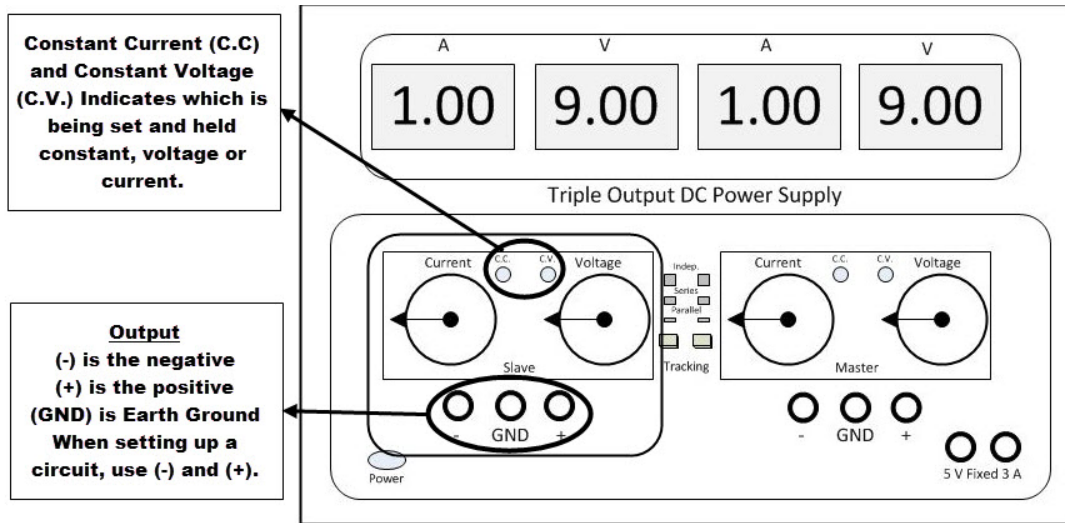


Figure 42: Triple Output DC Power Supply

Step 4: Connect the Power Supply to the Breadboard

- A common breadboard is shown below. Follow the manufacturer’s directions for your particular breadboard, or for similar breadboards, follow the directions below:
- Insert a red cable with banana plug into the POS (+) terminal of the Power Supply and the other end into the red terminal of the breadboard.
- Insert a black cable with banana plug into the NEG (-) terminal of the Power Supply and the other end into the GND terminal of the breadboard.
- Do NOT turn on the power supply at this time.

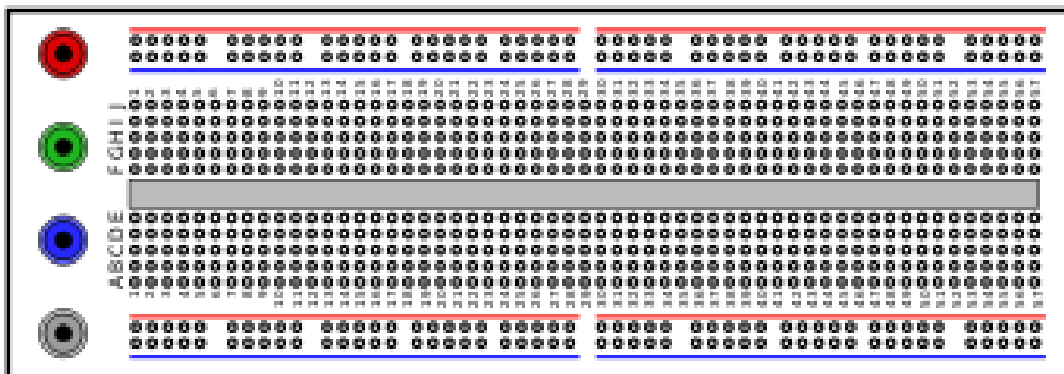


Figure 43: Typical Breadboard

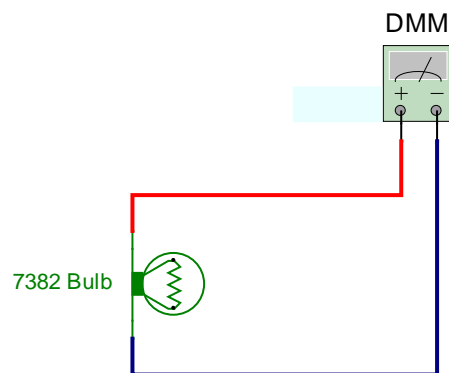
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Step 5: Set up the DMM

- When using a handheld DMM, remember to turn the dial to the appropriate setting (V, A, or Ω) and make sure it is set for DC circuits. For bench models, as soon as the power is turned on, press the correct button depending on what you are measuring.
- Insert the test leads into the proper jacks on the meter.
 - For voltage and resistance, the black lead goes to the “COM” and the red lead goes to “V/ Ω .”
 - For current, the black lead goes to “COM” and the red lead goes to the “A.”
 - Be aware that different meters will have different red jacks for current. If there are two red jacks, one is normally labeled 200 mA or 2 A MAX and the other 20 A MAX. For purposes of this course, there is no need to use the 20 A MAX jack as we will not be working with current amounts greater than 1 A.

Step 6: Measuring Resistance

- Before turning on the power supply, remove the bulb and measure the resistance between the leads. Record the measurement in Table 6.
- Return the bulb to the circuit and turn the power supply on. If the bulb does not light, review your circuit to ensure that there is continuity – make sure that the jumper wires are in the correct places to provide a closed path from the positive side of the power supply through the light bulb and back to the negative side of the power supply.

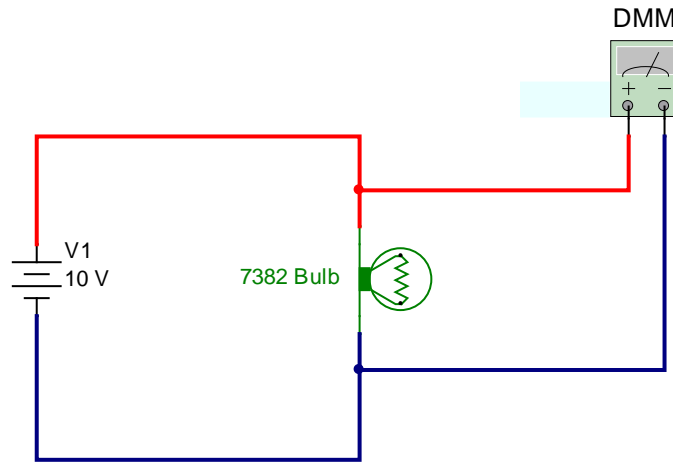


Circuit 2: Measuring resistance of bulb with DMM.

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Step 7: Measuring Voltage

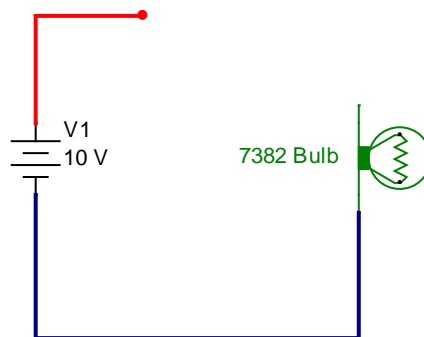
Using the DMM (bench or handheld), measure voltage and record in Table 6. Measure the voltage across the bulb by using small jumpers that are inserted in the same rows as the bulb. Because the rows are connected, the same amount of voltage will be measured across them.



Circuit 3: Measuring voltage drop across bulb.

Step 8: Measuring Current

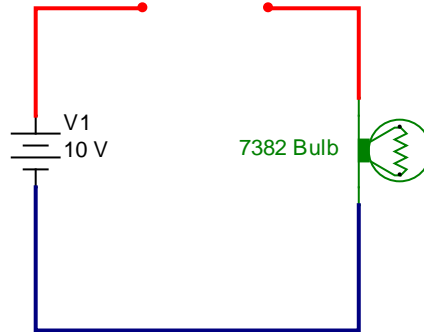
- Turn off the power supply and set up the circuit to measure Current following the steps below:
 - Insert the DMM into the circuit by disconnecting the jumper between the positive bus and the light bulb. Leave it plugged into the bus line, but unplugged from the bulb.



Circuit 4: Break open the circuit

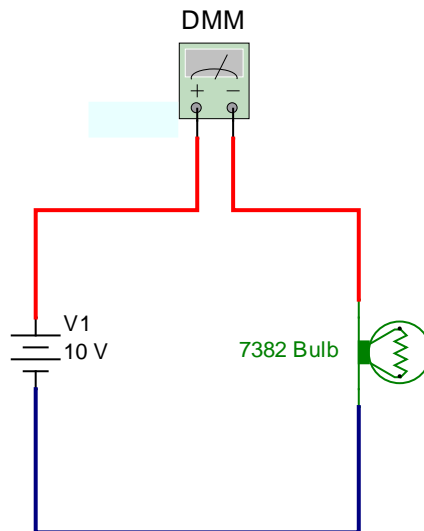
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- Insert a jumper wire on the positive side of the light bulb



Circuit 5: Attach jumper wire to bulb

- The positive lead of the DMM will go to the jumper on the positive bus and the negative lead will go to the jumper on the positive side of the bulb. Essentially, you have opened the circuit and have inserted the DMM into it. The current will now flow from the power supply, through the DMM, through the light bulb, and back to the power supply.



Circuit 6: Insert DMM

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- Before turning on the power supply, double check your set up to make sure that it is correct. If in doubt, ask your instructor to check your wiring.
- Record current in the Table 6.

Tables for Electricity Lab 1: Building a Simple Circuit

Resistance, Ω	Voltage, V	Current, mA

Table 6: Electricity Lab 1: Building a Simple Circuit

Observations and Conclusions

In your lab report, include your results from Table 6 as well as any observations or conclusions you may have made during this exercise.

Some questions to consider:

- When measuring resistance, why would you want to remove the bulb from the circuit first?
- When measuring voltage, if you were to remove the bulb from the circuit and measure between the jumper wires attached to the power supply, what reading would you get?
- When measuring current, what would happen if you attached the negative lead of the DMM to the positive side of the power supply and the positive lead to the negative side?

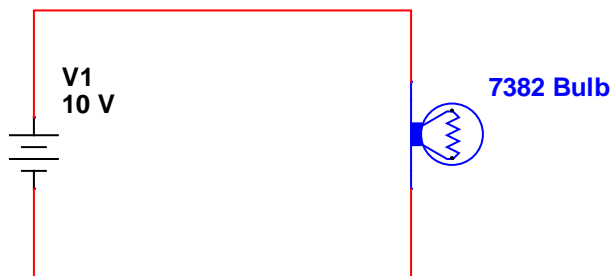
Electricity Lab 2: Using an Analog Meter

The directions below refer to a Simpson 260 VOM. For other makes and models, please refer to the manufacturer's instructions on how to properly set up the meter for measurement. Due to the real possibility of damage to the meter, only measurement for voltage will be taken. Because the bulb has low resistance and is also affected by the meter during resistance measurements, the three resistors will be used for resistance measurements.

Components & Equipment Needed

- Bread Board
- Wire (22 AWG)
- DC Power Supply
- Analog Multimeter or VOM
- 7382 Bulb
- Resistors: 1 Ω , 100 Ω , 10 k Ω , 1 M Ω

Circuit Diagram



Circuit 7: Electricity Lab 2 Circuit Diagram

Procedure

Step 1: Measuring Voltage with the VOM

- Set function switch at +DC
- Plug black lead into –COMMON jack and red lead into the + jack
- Set the correct range using the dial. If in doubt, always use the highest range setting to protect the meter
- Connect the black lead to the negative side of the circuit and the red lead to the positive side.
- Switch on the power supply.
- Measure voltage and record in table 8. As with the digital multimeter, measure the voltage across the bulb by using small jumpers that are inserted in the same rows as the bulb.

Step 2: Measuring Resistors

- For this section, the circuit and power supply will not be used. Instead, measure three resistors: 1 Ω , 100 Ω , 10 k Ω , 1 M Ω
- Turn range switch to appropriate resistance range:

R x 1	0 - 200 Ω
R x 100	200 – 20,000 Ω
R x 1000	Resistance above 20,000 Ω .

Table 7: Resistance Ranges

- Plug black lead into –COMMON jack and the red lead into the + jack
- Connect the ends of the leads together – if the reading is NOT zero; adjust using the “ZERO OHMS” knob until it does.
- Set function switch at + DC or –DC
- Record the measurement in Table 8.
- Repeat for each remaining resistor. Remember, the meter must be zeroed for each new resistor range.

Tables for Electricity Lab 2: Using an Analog Meter

Voltage, V	Resistance, Ω
	1 Ω =
	100 Ω =
	10,000 Ω =
	1,000,000 Ω =

Table 8: Electricity Lab 2: Using an Analog Meter

Observations and Conclusions

In your lab report, include your results from Table 8 as well as any observations or conclusions you may have made during this exercise.

Some questions to consider:

- Were there any accuracy issues when measuring the very small (1 Ω) or the very large (1 M Ω) resistors?
- Did you experience parallax error?

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Answers to Knowledge Checks

Matter

1. Anything that occupies space and has weight is matter. (TRUE)
2. An element is a substance which cannot be reduced to a simpler substance by chemical means. (TRUE)
3. Match the type of subatomic particle to the correct charge.

proton	Correct Answer	positive
electron	Correct Answer	negative
neutron	Correct Answer	neutral

Electrostatics

4. A negative charge is created in a neutral body by the accumulation of excess protons. (FALSE)
5. Static charge is the result of friction. (TRUE)
6. The electrical charge of an atom which contains 8 protons and 11 electrons is
 - a. Positive
 - b. Negative (CORRECT)
 - c. Neutral
7. What is the electrical charge of an atom which contains 4 protons and 4 electrons.
 - d. Positive
 - e. Negative
 - f. Neutral (CORRECT)
8. Like charges attract and unlike charges repel. (FALSE)

Energy

9. Choose the term which most accurately describes voltage or emf

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- a. Resistance
 - b. Current
 - c. Difference of Potential (CORRECT)
10. 3900 volts is the same as
- d. 3.9 mV
 - e. 39 mV
 - f. 3.9 kV (CORRECT)
 - g. 39 kV
11. Match the voltage type to the example of how it is produced.
- | | | |
|---------------|----------------|----------|
| Piezoelectric | Correct Answer | Pressure |
| Thermocouple | Correct Answer | Heat |
| Generator | Correct Answer | Magnetic |
| Battery | Correct Answer | Chemical |
| Photoelectric | Correct Answer | Light |

Electric Current

12. According to electron theory (Electron Current Flow), an electric current flows from the negative potential to the positive potential. (TRUE)
13. The effects of directed drift take place at what rate of speed?
- a. speed of light (CORRECT)
 - b. Speed of sound
 - c. 45,000 feet per second
 - d. 100,000 feet per second
14. Choose the most correct description of the relationship between voltage and current in a circuit.
- a. Voltage increases as current decreases
 - b. Voltage increases as current increases (CORRECT)
 - c. Voltage decreases as current remains steady
15. Convert 350 mA to amperes (A):

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- a. 0.35 A (CORRECT)
 - b. 35 A
 - c. 3.50 A
 - d. 3500 A
16. Convert 2.5 A to milliamperes (mA):
- a. 2.5 mA
 - b. 25 mA
 - c. 250 mA
 - d. 2500 mA (CORRECT)

Electrical Resistance and Conductance

17. Ω is the symbol for ohms (TRUE)
18. When weight is a major factor, which conductor would be used:
- a. Gold
 - b. Copper
 - c. Aluminum (CORRECT)
 - d. Silver
19. Select which wire has the least resistance:
- a. Copper, 1000 circular mils, 6 inches long
 - b. Copper, 2000 circular mils, 11 inches long (CORRECT)
20. Which temperature coefficient indicates a material whose resistance increases as temperature increases?
- a. Positive (CORRECT)
 - b. Negative
 - c. Neutral
21. $R = 1/G$ is the equivalent of $G = 1/R$ (TRUE)

Electrical Safety

22. What can cause a ground fault?
- a. Dirt build up on the power lines
 - b. Ground water
 - c. A tree branch
 - d. All of the above (CORRECT)
23. Electric shock can cause the following:
- a. Burns
 - b. Muscles to constrict and freeze
 - c. Death
 - d. All of the above (CORRECT)
24. When working on electrical equipment, why should you use only one hand?
- a. To allow for greater ease of eating or drinking while working on the equipment.
 - b. To ensure that the other hand cannot provide a path, such as a ground, for current to flow (CORRECT)
 - c. To allow for waving at your friends when they walk by.
 - d. None of the above
25. Effects of electric shock can be:
- a. muscular inhibition
 - b. Death
 - c. Respiratory Failure
 - d. All of the above (CORRECT)
26. Why don't birds get shocked when they sit on the high-voltage power lines?
- a. Because they have super-insulated feet.
 - b. Because they are extraordinarily lucky.
 - c. Because both the bird's feet touch the same point (electrically common) (CORRECT)
 - d. Because their bones are hollow

Equipment Safety and Use

27. When measuring AC voltage, if the test leads come into contact with one another while measuring the live circuit, there will be:
- an open circuit
 - a short circuit (CORRECT)
 - a long circuit
 - nothing
28. The most hazardous and complex application of the digital multimeter (DMM) is the measurement of
- Current (CORRECT)
 - Resistance
 - Voltage
 - Power
29. When measuring current,
- connect the ammeter in line, or in series, with the circuit being tested (CORRECT)
 - always start with the highest range of the ammeter
 - De-energize or discharge the circuit completely before connecting the ammeter
 - All of the Above (CORRECT)
30. When measuring voltage
- Always connect the voltmeter across, or in parallel with, the component being tested
 - always start with the highest range on the voltmeter
 - never use the dc voltage setting to measure ac voltage
 - all of the above (CORRECT)
31. When measuring resistance
- De-energize or discharge the circuit completely before connecting the ohmmeter
 - Do not apply power when measuring resistance.
 - Set the dial to “Resistance”
 - All of the above (CORRECT)

Additional Resources

Bread boarding Resources

- Vanderbilt University: “The Breadboard” (<http://eecs.vanderbilt.edu/courses/ee213/Breadboard.htm>)
- TechDose: “How to use Solderless Breadboards,” by Wayne Eggert (<http://www.techdose.com/electronics/How-to-Use-Solderless-Breadboards/252/page1.html>)
- Collin’s Lab: The REAL Breadboard (<http://www.youtube.com/watch?v=HrG98HJ3Z6w>)
- SNMU: How Breadboards Work (<http://www.youtube.com/watch?v=lqw6ask5HK0>)

Resources from All About Circuits

- Electrical Quantities A (<http://www.allaboutcircuits.com/videos/7.html>)
- Electrical Quantities B (<http://www.allaboutcircuits.com/videos/8.html>)
- Light and Other Waves (<http://www.allaboutcircuits.com/videos/9.html>)

Resources from Kahn Academy

- Electrostatics (part 1): Introduction to Charge and Coulomb’s Law (<https://www.khanacademy.org/science/physics/electricity-and-magnetism/v/electrostatics--part-1---introduction-to-charge-and-coulomb-s-law>)
- Electrostatics (part 2): Electric Fields (<https://www.khanacademy.org/science/physics/electricity-and-magnetism/v/electrostatics--part-2>)
- Voltage: Difference between electrical potential (voltage) and electrical potential energy (<https://www.khanacademy.org/science/physics/electricity-and-magnetism/v/voltage>)

Massachusetts Institute of Technology (MIT)

- *The Wonders of Electricity and Magnetism* by Walter Lewin, Professor of Physics (<http://mit.tv/zWLrk4>)

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