

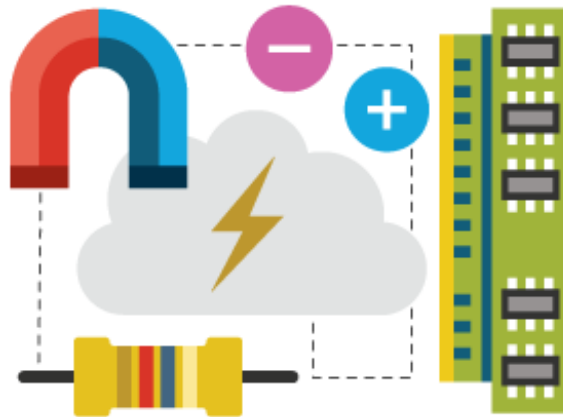
Nature of Electronics : Nature of Electricity

Lesson 1 Overview

Electricity is one of our most important forms of energy. Without electricity, no plant could operate as it does today, and industry as we know it wouldn't exist.

Every person who works in industry needs to know

something about the nature of electricity; that is, what it is and how we use it. This lesson, your first in basic electricity, will introduce you to many of the important fundamental concepts relating to electricity.



1.1 Explain the operation of simple circuits, conductors, insulators, and resistors

Introduction to Electricity

READING ASSIGNMENT

Electricity is a natural force produced by the movement of electrons. The most common natural source of electrical energy is lightning. Of

course, the energy produced by a burst of lightning is much too strong to be harnessed for use in homes and businesses. Therefore, the electrical energy we use every day is produced artificially in generating plants and by equipment, like solar panels, which harness renewable energy resources.

It's hard to overstate the importance of electricity to today's homes and industries. Electrical power is used for lighting, heating, air conditioning, and running home appliances. Manufacturing plants use electricity to run processing equipment, control systems, and computers. Millions of present-day jobs would be radically different or nonexistent without electricity. We couldn't live the way we're used to without electricity. If you doubt that, think about the panic that occurs when your lights go out or when your bank's computer shuts down!

The History of Electricity

Humans have experienced the effects of electricity since ancient times. Early men and women observed the effects of lightning, magnetism, and static electricity without understanding where these forces came from or what caused them.

The first experiments with electricity were performed about 600 BCE in ancient Greece. The Greeks noted that when the mineral amber was rubbed against fur, the amber gained the ability to attract small objects. Today, we understand that this attraction is caused by static electricity. However, in ancient Greece, there was no real understanding of this phenomenon and no practical application for it.

By the fifteenth century, scientists had begun to examine natural forces more closely and develop theories about them. Over the next several hundred years, scientists such as Alessandro Volta, Georg Ohm, James Joule, and James Watt made important discoveries about electricity, magnetism, and physics. All of these men gave their names to electrical properties and units (volt, ohm, joule, and watt).

In America, an important advance in electrical studies was made in 1752 when Benjamin Franklin performed his famous experiments with lightning and kites. Franklin attached a metal key to a kite string and sent the kite sailing into a lightning storm. He then observed the discharge of lightning near the kite. When he reeled in the kite, he moved his hand near the key and saw a spark of electricity. Franklin observed that the lightning was an intense electrical discharge between the negatively charged lower portion of thunderclouds and the positively charged earth. His observations provided important insights into the nature of electricity.

Popular retellings of Franklin's kite experiment claim that lightning struck either the kite or the key directly. Modern science tells us that this scenario is highly unlikely: if lightning had directly contacted the kite wire, Franklin most likely would have been killed due to the high electrical charge in the wire. To put it in perspective: a 100 ampere current is enough to cause a fatal injury, while lightning bolts can carry 200,000 amperes or more.



[An image of a telegraph, telephone, and electric light]

The telegraph, telephone, and electric light were three of the first practical uses of electricity.

The nineteenth century saw the practical application of electrical principles to commercial products and devices. The first truly successful application of electricity was made in 1837 with the telegraph. The telephone was patented in 1876 by Alexander Graham Bell; then came the incandescent light, invented by Thomas Edison in 1878. These devices changed the world and kicked off a new age of electrical study and invention.

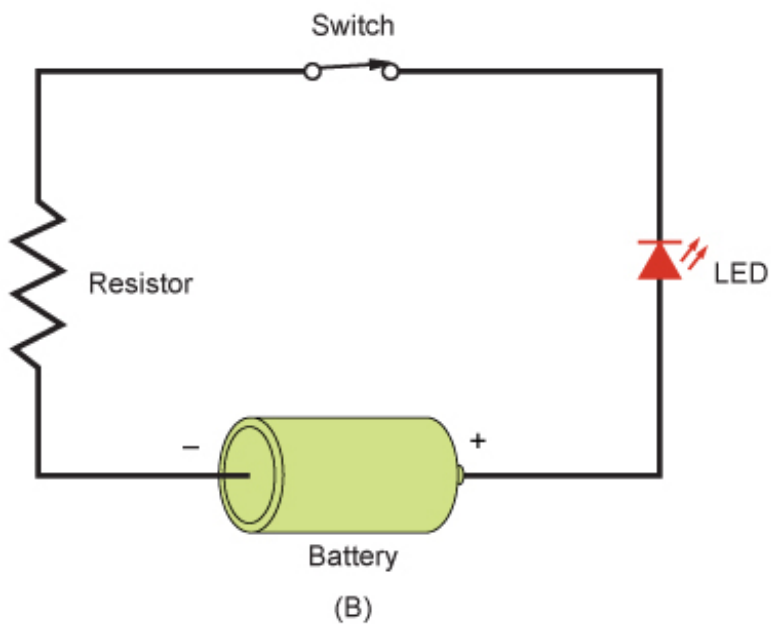
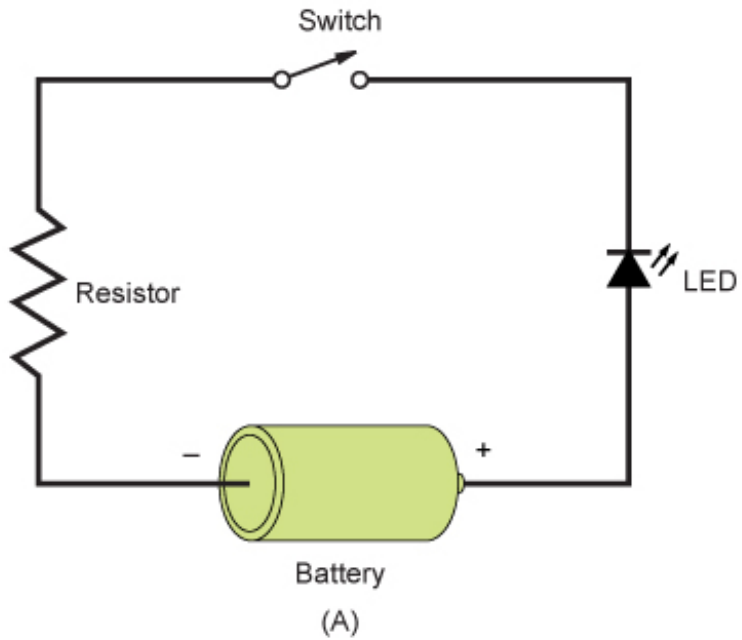
Now that you understand a little about the importance of electricity and its history, you'll examine how electricity is used today.

A Simple Circuit

As an electrician or technician in an industrial environment, you'll need to know how electricity is generated, distributed, used, and controlled. You can start the learning process by looking at a simple circuit. Examining the basic structure and components of a circuit will help you better understand the material you'll study later in this text.

A *circuit* is defined as a complete electrical path. A typical circuit includes a power source, conductors, a load, and a switch. The *power source* in a circuit is typically a wall outlet or a battery. The *conductors* are the wires that carry the electricity. The *load* is a device, such as a light or an appliance, that you want to run with electricity. The *switch* is the device used to turn the electricity flow on and off.

In a circuit, when the switch is turned on, electrical power from the power source flows through an unbroken path to the load. This is called a *closed circuit* because the circuit is complete—the power flows through the entire circuit path. When the switch is turned off, the path of the circuit is broken, and power can't flow to the load. This is called an *open circuit*.



[An image of an open and closed electrical circuit for a flashlight]

This figure illustrates a simple electrical circuit. In (A), the switch is open, so electricity can't flow to the LED. In (B), the switch is closed, allowing electricity to reach

the LED and light it.

A simple flashlight circuit is shown in the figure. The power source in this circuit is a battery. The conductors are copper wire. The load is a *light emitting diode*, or *LED*, and a *resistor*. You'll soon learn more about resistors. For now, it's enough for you to understand they're devices that restrict the flow of electricity without completely blocking it. In A, the switch is open (turned off). The electrical circuit is therefore open, and power can't flow through the wires and reach the LED. In B, the switch is closed (turned on). The circuit is therefore complete, and electricity can flow through the wires to the LED and turn it on.

Now you understand what a circuit is, but you still haven't learned exactly how the electrical power is created. Well, you learned earlier that electricity is the movement of electrons. *Electrons* are tiny atomic particles that have a negative electrical charge. In the circuit shown in the figure, moving electrons come from the battery. The battery produces a flow of electrons that moves through the wires to light the LED.

Now you'll take a closer look at the battery and how it produces electrical power. Note that the battery has two different ends, and each end is labeled differently. The end of the battery that's labeled with a negative sign (–) is called the *negative terminal*. The opposite end of the battery is marked with a positive sign (+) and is called the *positive terminal*. The negative terminal of the battery contains *too many* electrons. The positive terminal of the battery contains *too few*

electrons.

It's a law of nature that whenever too many electrons are in one place, the electrons will move to a place where there are fewer electrons. That is, these opposite forces attract each other. So, the electrons at the negative terminal of the battery are drawn toward the positive end of the battery.

If you attach wires to the two battery terminals, you create a path for the electrons to follow from the negative end of the battery to the positive end. By attaching the conductors, you're "building a road" between the two terminals. Then, when the switch is turned on and the circuit is closed, the electrons from the negative terminal of the battery are drawn to the positive terminal. As the electrons flow through the LED it glows, producing visible light. The flow of electrons through a circuit is called *electric current*.

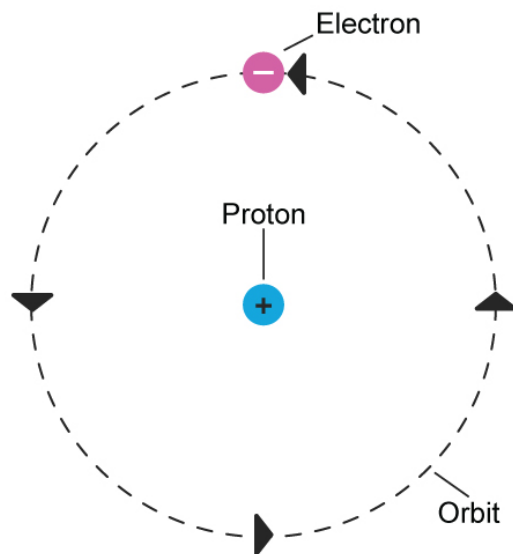
Atoms and Electrons

You've just learned that electrons must flow through a complete circuit in order for the circuit to work, and you've learned that electrons are atomic particles. What exactly does this mean? To answer that question, you'll need to look at the structure of an atom.

All matter in the universe is formed from about one hundred or so different substances called *elements*. Each different element, such as gold, silver, or oxygen, is made up of its own unique gold, silver, or oxygen atoms. An *atom* is the smallest particle of an element that still

keeps the properties of the element.

All atoms are made up of tiny atomic particles called *protons*, *neutrons*, and *electrons*. The *electron* is a very lightweight particle that has a negative electrical charge. *Protons* are much heavier than electrons (about 1,840 times heavier) and have a positive charge. *Neutrons* have no electrical charge at all—they're neutral. Electrons are the smallest type of atomic particle; they're much smaller than the atom as a whole.



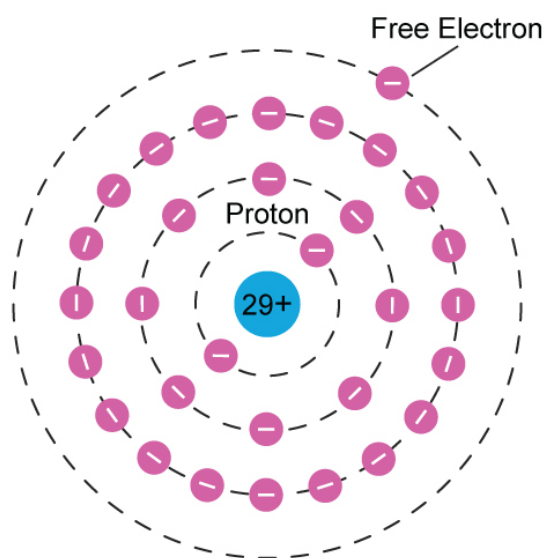
[An image of a hydrogen atom containing one proton and one electron]

A single atom of hydrogen contains one proton and one electron. The proton is represented by the circle with the plus sign (+) inside. The

electron is represented by the circle with the minus sign (–) inside.

Now, you'll look at an atom. The figure shows a drawing of a hydrogen atom, the simplest atom known. A hydrogen atom contains one electron and one proton. The proton is located in the *nucleus* (the center) of the atom. The electron orbits around the nucleus, just like the moon orbits around the earth. All atoms are constructed in the same general way as the hydrogen atom, but the number of protons, neutrons, and electrons varies with each different substance.

The hydrogen atom is perfectly balanced electrically. The atom contains one positively charged proton and one negatively charged electron; the proton and electron balance each other out. Because of this balance, the electron in a hydrogen atom is tightly attached to the proton. The electron can't easily be removed from the atom.



[An image of a copper atom

containing a single free electron in its outermost orbit]

A copper atom contains a single electron in its outermost orbit. This free electron can be dislodged easily from its orbit.

Now, in comparison, look at an atom of copper. The copper atom contains 29 electrons and 29 protons. The electrons orbit the nucleus of the copper atom in several layers called *shells*. The outermost shell contains only one electron, called a *free electron*. Since the free electron is alone and very far away from the atom's nucleus, it can be dislodged from its orbit easily.

In general, protons and neutrons can't be removed from an atom easily. However, in some atoms, *electrons* can be removed easily. You already know that electric current is produced by the movement of electrons. Well, to get the electrons moving, they're removed from one atom and inserted into the outer shell of the next atom.

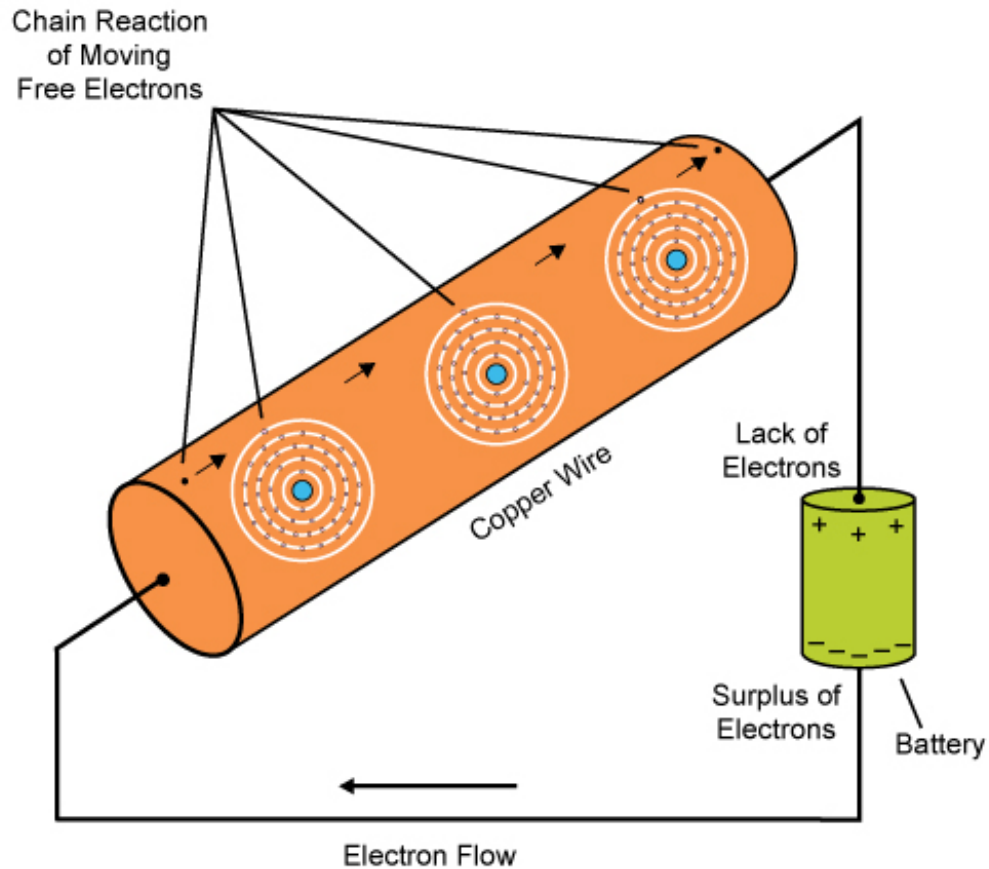
Electrons can be removed from atoms in a variety of ways. For example, when light strikes some substances, electrons may be dislodged from the substance. Another common way to remove electrons from a substance is through *friction* (rubbing).

The structure of an atom determines how easily an electron can be removed from it. For example, you saw that the structure of the hydrogen atom makes it difficult to remove an electron from its orbit.

Because of this, it's very difficult to get electrons moving in hydrogen. However, in the copper atom, the outermost electron can be removed from its orbit easily. Therefore, it's very easy to produce a flow of electric current in copper atoms. (This property is why copper is used in electrical wires and cables.)

The number of electrons that an atom contains, and how easily those electrons can be dislodged from their orbits, is very important in our study of electricity. Any substance in which electrons can move freely is called a *conductor*. Atoms that are tightly bonded are very poor conductors of electricity, while atoms that contain free electrons in their outer shells (like copper) are excellent conductors of electricity. We'll discuss conductors in more detail a little later.

The Flow of Electrons in a Circuit



[An image of a simple circuit in which a copper wire is attached to a battery]

In this magnified view of a simple circuit, a free electron from the battery enters the copper conductor wire. As the battery electron enters the wire, it displaces free electrons from the copper atoms in the wire, creating a “chain reaction” of moving electrons.

Now that you understand more about how atoms are constructed, you’ll examine how electrons flow within an electrical circuit. The figure of a simple circuit shows a copper wire attached to a battery. One section of the copper wire is enlarged so that you can see the individual copper atoms that make up the wire. The battery in this

figure has a negative terminal (–) and a positive terminal (+). There are too many electrons at the negative end and too few electrons at the positive end. In the figure, the circuit is closed, and the electrons from the negative battery terminal are drawn to the positive terminal.

So, an electron is drawn from the negative terminal of the battery into the copper conductor wire. This electron then collides with a free electron in a copper atom, bumping the copper electron out of orbit and taking its place. The displaced copper electron moves to a neighboring copper atom, bumps another free electron out of orbit, and takes its place. As this “chain reaction” continues, each free electron bumps its neighbor out of orbit and takes its place. The electrons keep pushing each other along until a free electron reaches the end of the conductor wire and moves into the positive terminal of the battery. This chain reaction of moving electrons is electric current.

In reality, we can't follow the movement of just one electron through a wire. Many millions of tiny copper atoms make up a wire. When a circuit is closed, millions of electrons move through the wire at the same time, and at a very, very high rate of speed.

Conductors, Resistors, and Insulators

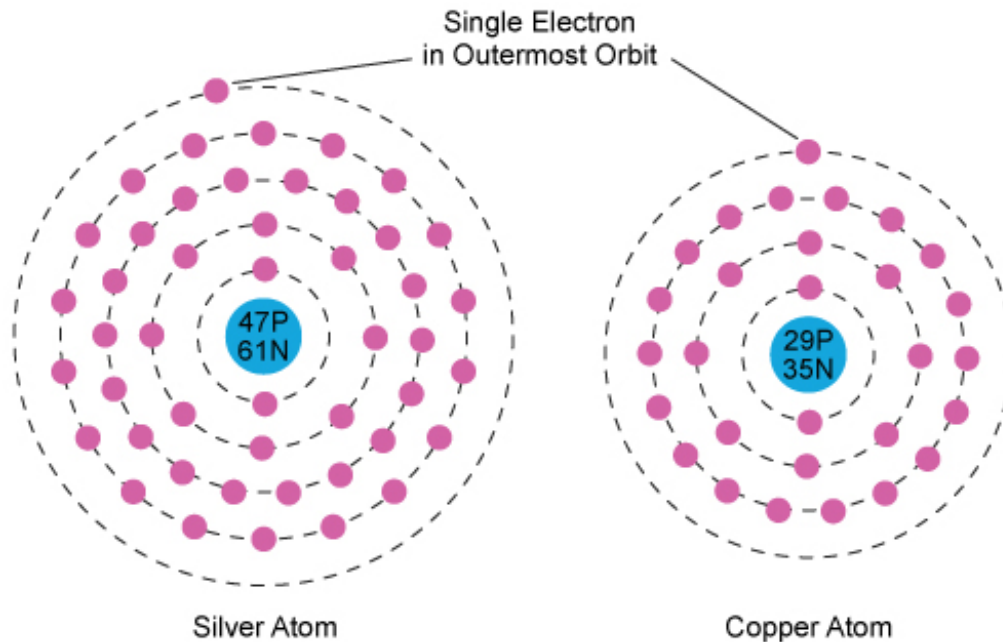
One of the first scientists to observe the flow of electrical current through various materials was Georg Ohm. In the early 1800s, Ohm performed experiments with electric current. He found that when current was applied to different materials, some materials carried the current readily and others didn't. He found that different materials put

up different degrees of resistance to the flow of electricity.

For example, he noticed that silver and copper readily permitted the passage of almost all of the applied electricity; therefore, he called these metals *conductors*. Some materials carried almost no electricity, even when a very high voltage was applied. Ohm called these materials *insulators*. Examples of insulators are glass, mica, porcelain, paper, plastic, and rubber. Other materials passed some (but not all) of the current, so these were called *resistors*. Carbon is an example of a resistor.

Using your knowledge about the structure of atoms, you can now explain the results of Ohm's experiments. You learned that some atoms are constructed with free electrons in their outermost orbits. A material in which electrons can be moved easily from one atom to another by an outside force is a good conductor of electricity.

In comparison, other materials are made of atoms in which the electrons are very tightly bound to their orbits. In these atoms, it's very difficult to remove electrons from their orbits, so the material is a poor conductor of electricity. If the electrons in an atom can't be moved from their orbits at all, the material is an insulator. If at least some of the electrons can be moved, the material is a resistor.



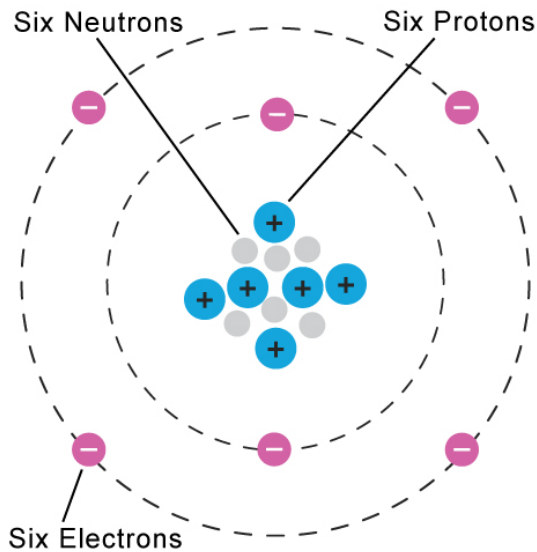
[An image of the atomic structures of silver and copper; both have only one electron in their outer orbit making them excellent conductors of electricity]

Atomic Structures of a Silver Atom and a Copper Atom

Two of the best-known conductors of electricity are silver and copper. The atomic structures of the silver and copper atom are compared in the figure. Note that both atoms have only one electron in the outermost orbit. This property makes silver and copper excellent conductors of electricity.

Silver is actually an even better conductor than copper. Why? Well, even though both silver and copper atoms have free electrons, the free electron in silver is farther away from the nucleus than the free electron in copper. The farther the free electron is from the nucleus, the more loosely bound the electron will be to the nucleus. This explains why silver, which has five electron orbits, is a better

conductor than copper, which has four orbits. Silver is often used as a coating on electrical conductors to keep the resistance as low as possible.



[An image of the atomic structure of carbon; four electrons in its outer orbit make it a poor conductor of electricity]

An atom of carbon has four electrons in its outer orbit. These electrons aren't easily dislodged from their orbit, so carbon is a poor conductor of electricity.

Now, look at an atom of carbon. The nucleus of the carbon atom contains six protons and six neutrons. Six electrons orbit the nucleus. Now, look more closely at the electrons. Note that the electrons orbit the nucleus in two rings, or shells. The inner shell contains two

orbiting electrons, and the outer shell contains four orbiting electrons. The inner two electrons are tightly bonded to the nucleus. The outer four electrons are more loosely bonded to the nucleus and can be dislodged from their orbit.

However, the four electrons in the carbon atom aren't dislodged as easily as the single free electron in a silver atom. Thus, carbon will conduct *some* electricity, but it's not as good a conductor as silver. For this reason, carbon is used to make *resistors*, which are devices placed in electrical circuits to reduce the flow of electricity. Resistors reduce the flow of electricity, but they don't stop it completely.

Materials such as glass and ceramic contain atoms that are very tightly bonded. These materials are therefore often used to make insulating devices. An *insulator* completely stops the flow of electricity in a circuit. You'll frequently see ceramic insulators at the top of power poles.

Conductivity is a measure of how well a material carries electricity. The Relative Conductivities of Metals table compares the conductivity of several metals you'll see often. Note that copper is used as a standard against which the conductivities of other materials are rated. For the purposes of comparison, copper is considered to be 100% conductive. The conductivity ratings of other materials are then expressed as percents relative to copper. Note that this doesn't mean that copper has no electrical resistance; it just means that copper is used as the standard that other materials are rated against. Silver, for

example, is rated 105 percent on the table. While silver isn't a *perfect* conductor of electricity, it's the best conductor. Insulated wire, current-carrying metallic components known as *bus bars*, wire terminals, and other electrical conductors are most often made of copper, which is much less expensive than silver.

While copper is given a conductivity rating of 100 percent in the table, it isn't a perfect conductor. All forms of copper offer some opposition to the flow of electrons in a circuit. That's why circuits that require very long current-carrying conductors or very high current levels are built using physically larger conductors, bus bars, and terminals. These components, which are said to have a larger *cross-sectional area*, provide enough space for the relatively unrestricted flow of electrons.

Relative Conductivities of Metals	
Metal	Conductivity Relative to Copper (%)
Silver	105
Copper	100
Gold	70
Aluminum	61
Nickel	22
Zinc	27
Brass	28
Iron	17

Tin	15
Phosphor bronze	15
Lead	7
Steel	3 to 15

The table also lists gold as a good conductor. You may be aware that gold-plated contacts are sometimes used in better electronic equipment. The reliance of gold as a conductor in this application has to do with gold's resistance to deterioration due to *oxidation*, a coating that forms when a substance chemically reacts with oxygen. You're probably most familiar with rust as a type of oxidation that occurs when iron or steel reacts with water and air, which of course contains oxygen. Copper becomes green when subjected to air and moisture. This green film on copper, which is also a form of oxidation, can cause a bad electrical connection in a critical electronic circuit. Applying a thin gold plating to copper contacts helps prevent oxidation and the resulting deteriorated electrical connection.

Key Points and Links

READING ASSIGNMENT

Key Points

- A circuit is a complete electrical path, and is comprised of a power source, conductors, a load, and a switch.
- The power source is usually a wall outlet or a battery; the conductors are the wires that carry the electricity.

- The load is the device to be run with electricity and the switch is the device used to turn the electricity flow on and off.
- When the switch is turned on in a circuit, electrical power from the power source flows through an unbroken path to the load.
- When the switch is turned off, the path of the circuit is broken and power can't flow to the load.
- Any substance in which electrons can move freely is a conductor.
- Materials that don't allow the free movement of electrons and carry little or no electricity are insulators.
- Materials that pass some, but not all of the current, are resistors.
- Resistors are placed in electrical circuits to reduce the flow of electricity, but they don't stop it completely.
- Conductivity is how well a material carries electricity.

Exercise: Working with Electricity

Respond to the following based on your reading.

1. A typical circuit includes what four components?
2. The difference between a closed circuit and an open circuit is the position of the _____.
3. The _____ of an atom float in shells around the atom's nucleus.
4. _____ are used to reduce the flow of electricity but don't stop it completely.
5. _____ is a measure of how well a material carries electricity.

6. _____ is the best conductor of electricity.
7. A/An _____ completely stops the flow of electricity.
8. Rank the following metals in order of conductivity from *highest* conductivity to *lowest* conductivity: brass, tin, steel, copper, gold.

Exercise Answer Key:

Exercise: Working with Electricity

1. A power source, conductors, a load, and a switch
2. switch
3. electrons
4. Resistors
5. Conductivity
6. Silver
7. insulator
8. Copper, gold, brass, tin, steel

1.2 List the dangers and benefits of static electricity

Static Electricity

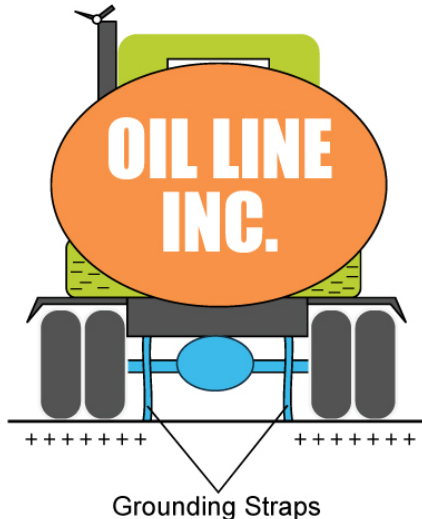
READING ASSIGNMENT

Charging by Friction

You know that electrical current is the movement of electrons through a circuit. Now, we'll examine another type of electricity—*static*

electricity. The word “static” means “standing still,” so static electricity doesn’t move. However, even though static electricity doesn’t move through a circuit, it still has much of the charge and power of electrical current. Static electricity can be very dangerous, especially in an industrial setting, so you must be aware of what it is and where it comes from.

Static electricity can be produced in two ways: by *friction* or through *induction*. Consider friction first. If you shuffle across a carpet, then touch a metallic surface, what would happen? You’d probably receive a small shock, and maybe even see a spark. This is an example of how static electricity is produced by *friction*, which occurs when one material rubs against another.



[An image of an illustration of a truck with grounding straps to transfer static charges back to the road]

Trucks that carry flammable liquids or chemicals must be carefully protected from static charges. The truck in this figure has grounding straps attached that drag along the road behind the vehicle. The straps transfer static charges from the truck safely back into the road.

When you walked across the carpet, your shoes rubbed free electrons from the carpet. Your body held onto those electrons. Any time that a material contains too many or too few electrons, the material is said to be *charged*. So, your body picked up a negative electrical charge from the carpet. When you touched the metallic surface, electrons from your body “jumped” over to the metal, restoring your body to a neutral charge. The discharge of electrons caused the small spark that you felt.

Static charges often develop on the rubber tires of moving vehicles. Friction with the road surface causes the tires to pick up electrical charges. To prevent these charges from building up on tires, some trucks have *grounding* chains or straps that drag behind them. The

chains or straps touch the road surface and release the static charges. These straps are commonly seen on gasoline trucks or similar vehicles that carry flammable or explosive substances, since a spark of static electricity could cause a fire or explosion.

Attraction and Repulsion of Charged Bodies

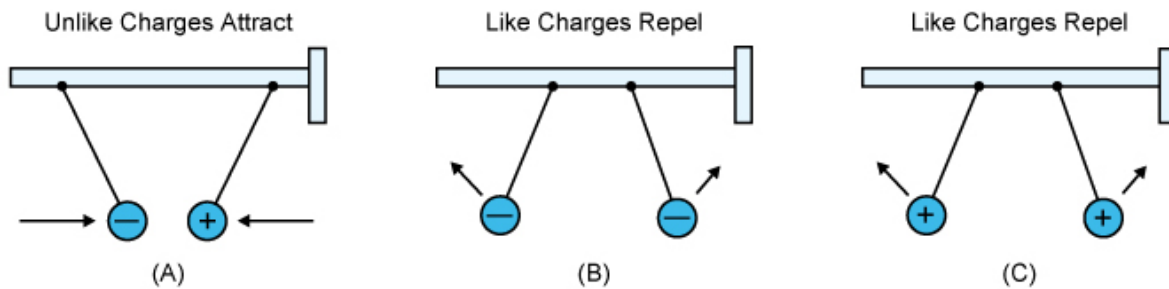
When a material is charged by friction, it becomes unstable, since it contains fewer or more electrons than normal. A material that has lost electrons through friction will gain a positive charge. A material that has gained electrons through friction will gain a negative charge. The material with the positive charge will be drawn toward the material with the negative charge. Therefore, a positively charged material will attract a negatively charged material, and vice versa.

It may be confusing to think that a material that *lost* electrons would have a *positive* charge. Just remember: until it loses or gains electrons, a material is balanced, meaning it has the same number of protons (positive charges) and electrons (negative charges). So, when the material loses electrons, it now has more protons (positive) than electrons (negative). Therefore, it has an overall positive charge.

At the same time, a positively charged material will *repel*, or push away, any other body that has a positive charge. A negatively charged material will repel another negatively charged material.

The figure of pith balls demonstrates the repel effect. *Pith balls* are very lightweight spheres. (*Pith* is a spongy material that's

similar to cork.) These pith balls are suspended from strings on a horizontal bar. In part A of the figure, one ball has a negative (-) charge and the other has a positive (+) charge. The two balls are so strongly attracted to each other that they pull together. If the pith balls touch, the charge will be neutralized, and they'll return to hanging straight down.



[An image of pith balls demonstrating unlike charges attract and like charges repel]

Remembering that unlike charges attract and like charges repel will aid you greatly in your understanding of electrical theory.

In part B, both pith balls are negatively charged. The balls repel each other so strongly that they move away from each other. In part C the two balls are positively charged; they also strongly repel each other.

The figure clearly demonstrates an important scientific principle: Opposite electrical charges attract each other and like electrical charges repel each other.

Pith balls are used to demonstrate the effects of attraction and repulsion because they're lightweight and easily moved by the static charges. Styrofoam also works well for this purpose due to its light weight. This video from the UC Berkeley Physics department shows

the [effect of static charges on styrofoam balls](http://www.youtube.com/embed/xQopII5_PBY?rel=0) (www.youtube.com/embed/xQopII5_PBY?rel=0) using cat fur to create a negative charge (by adding electrons) and saran wrap to create a positive charge (by removing electrons).

There are three rules that apply to the force of attraction and repulsion between charged bodies:

Rule 1: When two charged bodies are brought together, the stronger the charge, the greater the force of attraction or repulsion. Suppose you have two pairs of charged pith balls hanging from a bar. The distance between the balls is the same, but the first pair is more highly charged than the second pair. The first pair of pith balls will be more strongly attracted to or repulsed from each other than the second pair.

Rule 2: When two charged bodies are brought together, the closer they are, the greater the force of attraction or repulsion. Suppose you have two pairs of pith balls that have exactly the same charge, but the first pair hangs closer together than the second pair. The first pair will be more strongly attracted to or repulsed from each other than the second pair.

Rule 3: If the nonconductive substance or material between two charged bodies is thick enough, it can prevent the discharge of electrons from one body to the other. Suppose you have a pair of oppositely charged pith balls. Because the pith balls can't touch each other, they attract each other and move together. However, if you place a piece of rubber between the two balls, the balls can't touch

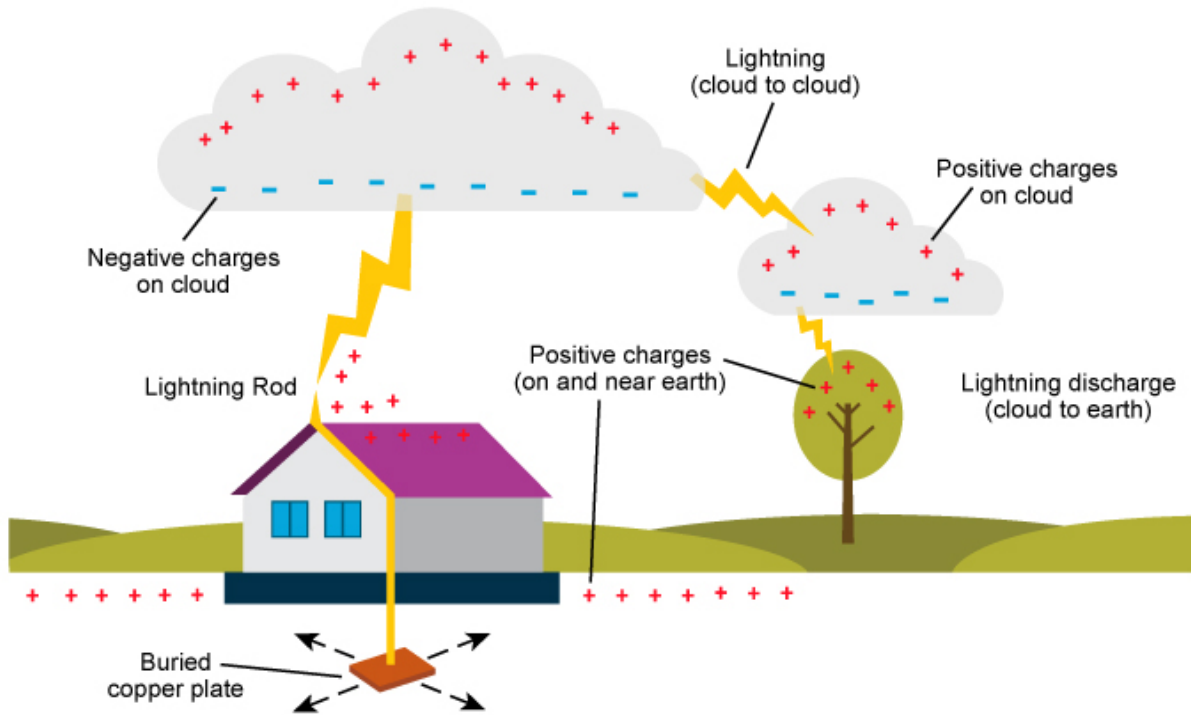
each other. The piece of rubber acts as a barrier, preventing electrons from moving from one ball to the other. While the charge on each ball remains the same, the rubber prevents a discharge of the static and the balls remain attracted to each other.

The material between one charged body and another is called the *dielectric*. In many cases, the dielectric is simply open air space. However, a dielectric could be any nonconducting material that comes between two charged bodies.

When electricity passes through the dielectric between two bodies, the dielectric is said to have been broken down or punctured. The dielectric between two charged bodies doesn't weaken the attraction or repulsion between them, but it does prevent the discharge of electricity from one body to the other until the attraction becomes strong enough to puncture the dielectric.

If two bodies with large and opposite charges are brought near to each other, the attraction between the opposite charges may become so strong that a spark of electricity will jump through the dielectric between the two bodies. The most extreme example of this occurrence is lightning. A lightning strike can occur between two clouds, between a cloud and a building, or between a cloud and the ground. During a lightning storm, opposing static charges build up in clouds and on the ground. The opposite charges attract each other, and when the attraction becomes strong enough, a very large spark of electricity jumps across the air space to strike the ground. The strike

neutralizes the opposite charges.



[An image of a diagram showing a lightning strike occurs when static charges build up so much the dielectric between them breaks down]

Lightning strikes occur when static charges build up to such a degree that the dielectric between the charges breaks down.

The Electric Series

Static charges commonly occur when two nonconducting substances (such as rubber and fur) are rubbed together. The substance that picks up the electrons gets a negative charge, while the substance that loses electrons gets a positive charge.

Materials can be rated according to the static charges they generate. The table provides a list of materials called the *electric series*. The

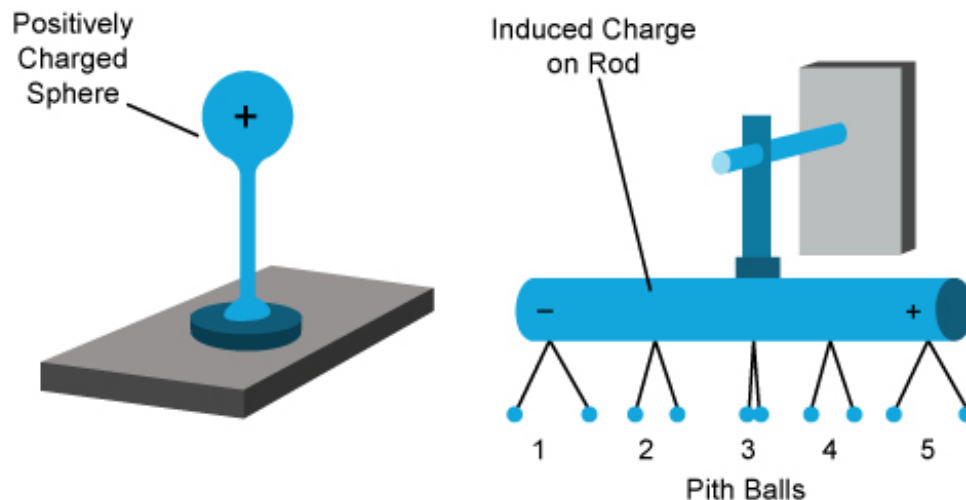
electric series contains a variety of materials listed according to their charges. The materials at the top of the list tend to lose electrons when rubbed against the materials at the bottom of the list. The materials at the bottom of the list gain electrons when rubbed against materials at the top of the list. So, for example, if you rub rabbit fur against hard rubber, the fur will lose electrons and take on a positive charge. The rubber will gain electrons and take on a negative charge.

Electric Series	
Most Positively Charged (+)	Air Asbestos Rabbit fur Flannel Glass Mica Human hair Nylon Wool Lead Silk Aluminum
Neutral (No Charge)	Paper Cotton Steel Wood Amber Sealing wax Hard rubber Nickel, copper Brass, silver Gold, platinum Sulfur Acetate rayon Polyester Celluloid Orlon® Saran Polyurethane Polyethylene Polypropylene Vinyl (PVC)
Most Negatively Charged (-)	Kel-F® Silicon Teflon®

The materials on the list may also take on a different charge depending on the material they're rubbed against. For example, if you

rub glass against rabbit fur, the glass will receive a *negative* charge because fur is above glass on the electric series. However, if you rub glass with silk, the glass will receive a *positive* charge because glass is above silk in the electric series. Thus, the placement of a material in the electric series list will indicate the charge it will receive when rubbed with another material.

Charging by Induction



[An image of a diagram illustrating the process of induction, in which an object receives a static charge by being placed near another charged object]

As the charged sphere moves close to the rod, a charge is induced on the rod and the pairs of pith balls move apart.

The nearness of the charged sphere to the rod determines how much charge will be induced on the rod.

You've just learned how a material can receive a static electrical charge through friction. Now, we'll examine how materials are charged

by *induction*, or the process by which an object receives a static charge by being placed near another charged object. If a charged body is placed near a neutral body, the neutral body will pick up a charge from the charged body. This process is illustrated in the experiment using pith balls that's shown in the figure. Five pairs of pith balls are suspended from a rod. A sphere is charged by friction and moved near to the rod. The rod then picks up a charge from the sphere.

Note that the rod acquires a negative charge on one end and a positive charge on the other end. When the positively charged sphere is brought close to one end of the rod, the electrons on the rod are attracted to the end of the rod that's closest to the sphere. This happens because unlike charges attract. Therefore, the end of the rod nearest to the sphere gets a negative charge, and the opposite end of the rod gets a positive charge. The middle of the rod remains electrically neutral.

As a result of a charge being induced on the rod, the pairs of pith balls also become charged. Each pith ball within a pair receives the same charge, so the balls repel each other and move apart. The induced charge on the rod is strongest at the ends, so the pith balls at the ends of the rod (pairs 1 and 5 in the figure) separate widely. The pith balls closer to the center (pairs 2 and 4) separate a little. The pith balls at the center of the rod (pair 3) remain neutral and don't separate.

When the sphere is withdrawn from the area near the rod, the two

charged ends of the rod neutralize each other, and the pith balls lose their charge and hang straight down. The pith balls can be made to separate and come together merely by moving a charged body near to or away from the rod.

The Dangers of Static Electricity

In many industrial plants, the presence of static electricity can be very dangerous. Static charges and the shocks that result can injure workers, damage equipment, or destroy sensitive electronic devices. Static electricity can cause explosions and create a fire hazard in locations where dust from coal, grain, feed, flour, starch, aluminum, or magnesium is present. Also, in any areas where flammable liquids are loaded, unloaded, and stored, a great deal of care must be taken to eliminate static charges.

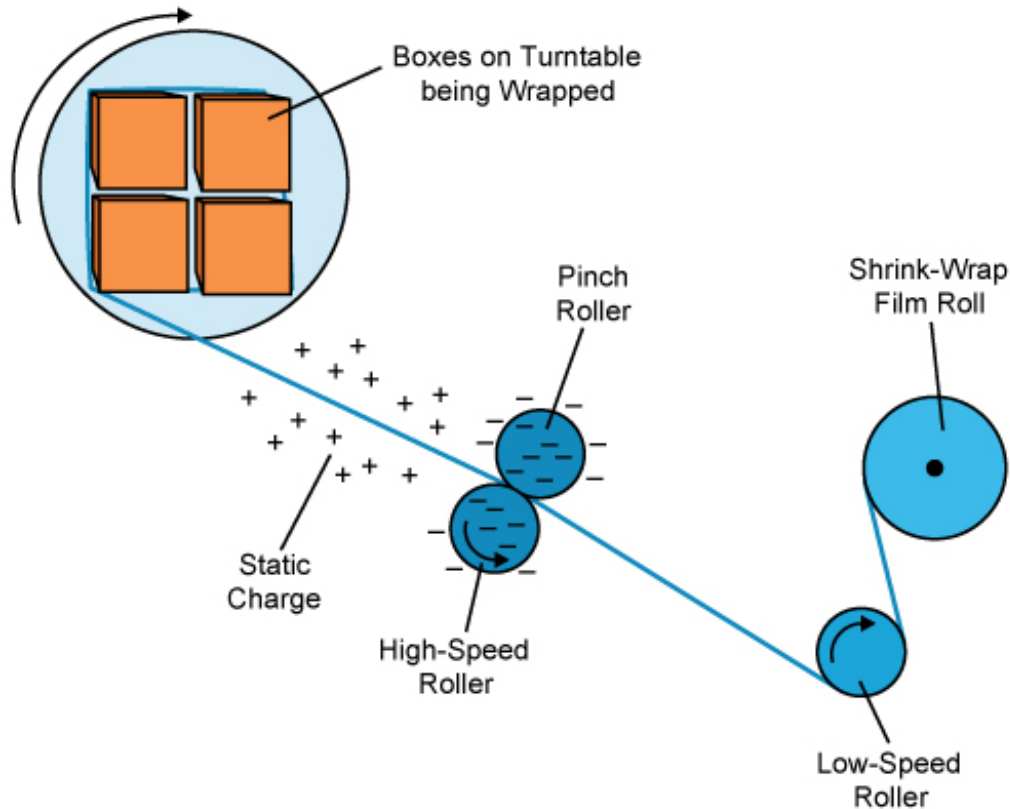
Static charges can be eliminated from metal components and equipment by either bonding or grounding. In *bonding*, a metal wire or strap is connected between two metallic surfaces or objects. The strap creates an electrical connection. In *grounding*, a metal object is connected to the earth through a *grounding device*, which is simply a pipe or rod driven into the earth. When static charges build up in the object, the bonding strap or grounding device will conduct the charge from the object into the earth, neutralizing the charge.

Sometimes bonding and grounding techniques are used together. One industrial example of bonding and grounding is seen in railroad tracks. In areas where tank cars are loaded or unloaded, the joints of rails are

usually bonded together with metal straps and then grounded to get rid of static charges.

Grounding is also commonly seen at gas stations. When you're at a gas station, you may notice that the nozzle on the gas tank is connected to a nearby grounding device. The grounding device may be a metal pipe or rod driven into the earth, or perhaps a metal water pipe. Grounding the gas nozzle prevents static discharges that could cause an explosion.

Static charges often build up on pieces of industrial equipment. For example, static charges frequently build up on machine belts because of the friction between the belts and the pulleys that drive them. The static charge may become strong enough to shock anyone who stands near the belts or touches the machine. In some industrial plants that wind material on rolls, the static electricity generated on the rolls can exceed 30,000 volts.

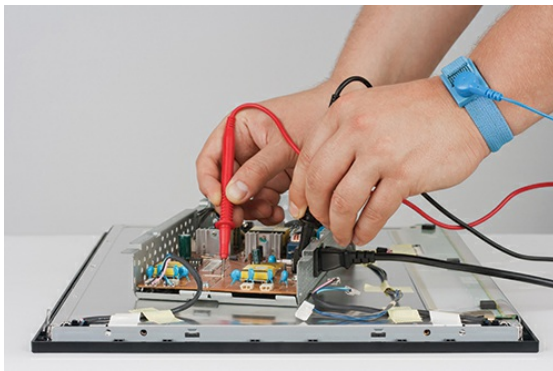


[An image of a shrink-wrap machine showing how static electricity can be generated by friction]

This top view of a shrink-wrap machine shows how static electricity can be generated by the friction of the high-speed roller on the shrink-wrap film.

One machine that generates a large amount of static electricity is a shrink-wrap machine. The clear plastic shrink-wrap is fed through two rollers that turn at different speeds. These rollers stretch the wrap out to as much as two hundred percent of its normal size to prepare it for application to a product. This process creates a lot of friction, and as a result, the roller becomes negatively charged and the wrap becomes positively charged.

Once the shrink-wrap is applied to a product, it shrinks back to its normal size, but it remains charged with static electricity. A grounded rod with electrical contacts can be touched to the wrapped products to eliminate the static charge. The grounding contacts are pointed because static electricity is more easily discharged onto a sharply pointed object than a rounded one. (This is the same reason why lightning rods are pointed.)



[An image of a worker wearing a grounding wrist strap to prevent static charges from damaging the electronic equipment being handled]

This worker is wearing a grounding wrist strap to prevent static charges from damaging the electronic equipment being handled. Straps like this one contain a resistor, which reduces the hazard of electrical shock to the person wearing it.

Industrial workers must always be on the alert for buildups of static electricity. In many industrial settings, static sparks from any source could have disastrous results. For example, modern solid-state electronic devices are so closely packed with transistors that a small static charge can destroy them. For this reason, workers must use extreme caution when they're handling circuit boards, computer components, and other electronic devices. When handling electronic components, workers should stand on antistatic floor mats and wear grounding straps on their wrists to prevent static discharges. Antistatic liquids are available that can be sprayed on workstations. Finally, electronic devices (particularly computer components and circuit boards) are packaged in special conductive materials to prevent damage from static electricity. Sensitive electronic devices you encounter are often packed in pink, gray, or black bags intended specifically to eliminate this type of damage.

Even if a work environment is relatively safe and machinery is shielded from static charges, a worker standing near a charged machine can pick up a static charge, then carry the charge into a hazardous area. To prevent this, conductive shoes and clothing must be worn in places where flammable materials are handled and in computer rooms, where static sparks can disrupt a computer's programming or destroy its circuits. Floors in these areas should also be covered with a static-reducing material.

The *National Fire Protection Association (NFPA)*, developer and sponsor of the *National Electric Code (NEC)*, covers the subject of

static charges in great detail in its code pamphlets. All industrial workers who deal with electricity should be familiar with the contents of the NEC.

Positive Uses of Static Electricity

So far, we've discussed only the negative aspects of static electricity. However, static electricity can be put to good use. For instance, static charges are used in a copying machine to attract ink onto a piece of paper. Static charges are also used in certain air filters. In an electrostatic air filter, air passes between metal plates that are highly charged with opposite voltages. Dust and foreign particles are attracted to the plates. Static electricity is also used in certain spraypainting and other coating processes.

For example, *powder coating* is a process that's very popular in industry. The application process directs the coating, in powder form, which is suspended in a stream of air delivered by manually or robotically controlled spray guns. At the end of the spray gun is a nozzle that incorporates an electrode, which applies thousands of volts of electrical charge to the powder as it flows by. The parts requiring coating are either grounded themselves or mounted on a conveyor, which is electrically grounded. The voltage difference between the charged powder and the grounded part generates heat that melts the powder onto the part, creating a very strong coating. By controlling the current and the voltage applied to the powder exiting the spray gun, the process regulates the powder's attraction to even

highly irregular surfaces on the part while also determining the coating thickness.

Key Points and Links

READING ASSIGNMENT

Key Points

- Static electricity is electricity that doesn't move through a circuit; however, it has much of the charge and power of electrical current.
- Static electricity is produced either by friction or through induction.
- Any time a material contains too many or too few electrons, it's said to be charged.
- If two bodies with large and opposite charges are brought near to each other, the attraction between the opposite charges can become strong enough that a spark of electricity will jump through the dielectric between the two bodies.
- Friction is created when two materials rub against each other.
- Induction is the process by which an object receives a static charge by being placed near another charged object.
- With induction, if a charged body is placed near a neutral body, the neutral body will pick up a charge from the charged body.
- Static charges and the shocks that result can injure workers, damage equipment, or destroy electronic devices.
- Static electricity can cause explosions and create a fire hazard

when there is dust or flammable liquids present.

- Static charges can be eliminated from metal components by either bonding or grounding.
- Static electricity can be put to good uses.
- Static charges are used in a copier to attract ink onto a piece of paper, and are used in air filters and spray painting and other coating processes.

Links

- [Effect of static charges on styrofoam balls](http://www.youtube.com/embed/xQopII5_PBY?rel=0) (www.youtube.com/embed/xQopII5_PBY?rel=0)

Exercise: Basics of Static Electricity

Fill in the blanks.

1. When two nonconducting substances (such as glass and fur) are rubbed together, the substance that picks up electrons from the other substance acquires a _____ charge.
2. An important rule concerning static charges is that like charges _____ each other.
3. A lightning strike occurs when _____ charges develop between a cloud and the earth.
4. According to the electric series, if you use a dry flannel cloth to polish a wooden table, the table will have a _____ charge when you finish.

5. Static electricity can be generated by friction and by _____.
6. Two methods used to eliminate static charges are bonding and _____.

Exercise Answer Key:

Exercise: Basics of Static Electricity

1. negative
2. repel
3. unlike
4. negative
5. induction
6. grounding

1.3 Define the terms volt, ampere, and ohm

Electricity in Motion

READING ASSIGNMENT

Electric Current

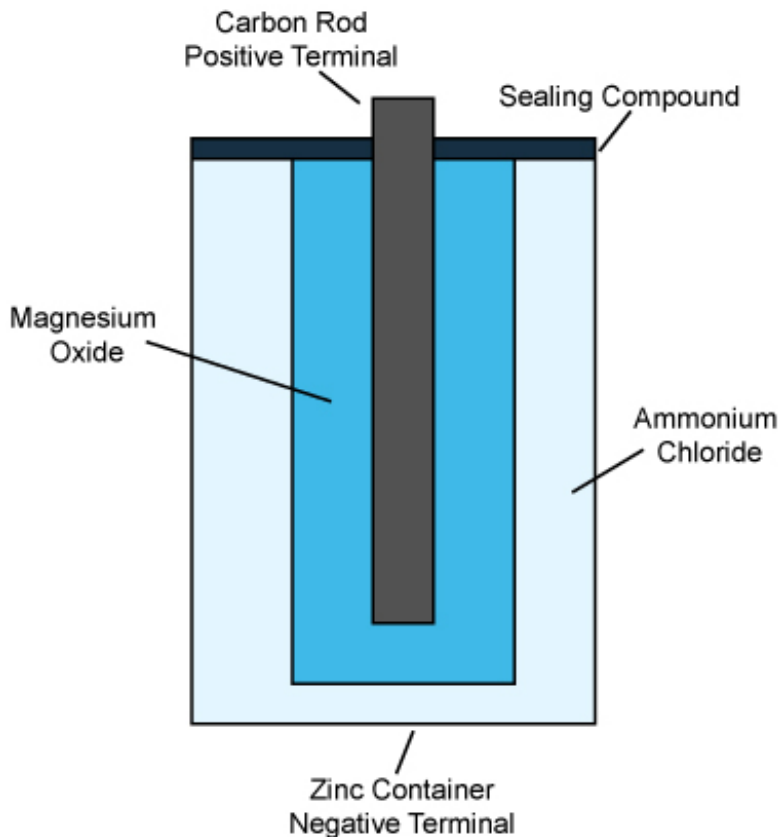
You've learned that static (unmoving) electricity exists wherever a material has either a positive or a negative charge.

If one charged material is brought close to a material with the opposite charge, electrons will be discharged from the negative material to the positive, leaving both materials neutral. Static electricity has only a few

useful applications in industrial settings. The main source of electrical power for running equipment, heating, and lighting is electric current.

There are two basic types of electric current that you must learn about: direct current and alternating current. *Direct current*, or *DC current*, is the flow of electrons in one direction, maintained by constant or uninterrupted voltage. Direct current is more commonly used by electronics technicians than by electricians. *Alternating current*, or *AC current*, is the flow of electrons first in one direction and then in the opposite direction. Alternating current or *AC current* is used most often in homes and industries. However, you must completely understand direct current first before moving on to study alternating current.

Batteries



[An image of a simplified view of the structure of a dry cell battery]

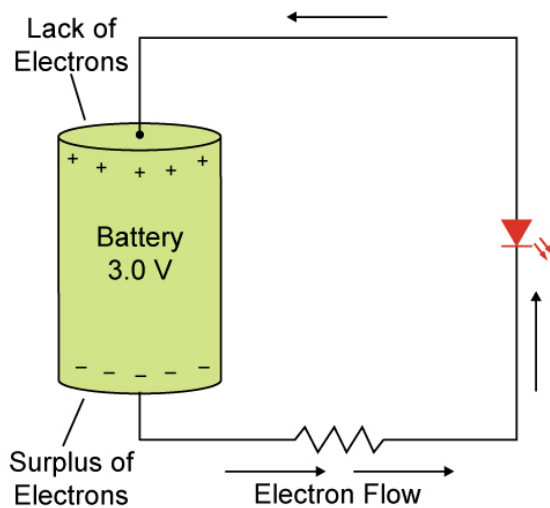
This figure is a simplified view of the structure of a dry cell battery.

The best example of a source of direct current can be seen in the common battery. A *dry cell* battery is composed of a zinc shell filled with a two-part chemical paste called an *electrolyte*.

A carbon rod is inserted into a *magnesium oxide* paste. The rod and the magnesium oxide paste are then contained within the second paste, made from *ammonium chloride*, and the zinc shell. As a result, a chemical reaction occurs within the battery, and a lack of electrons

develops at the carbon rod. The carbon rod becomes the positive battery terminal and is labeled with a positive sign. At the same time, in the battery, a surplus of electrons develops in the zinc shell. The zinc shell becomes the negative battery terminal and is labeled with a negative sign. The figure shows a simplified drawing of the structure of a dry cell battery.

The Flow of Direct Current



[An image of a simple circuit demonstrating electron flow theory]
Electron flow theory is shown here. Remember that a direct current is a continual flow of electrons in the same direction. A common source of direct current is a battery. In the circuit illustrated here, electrons

move from the negative (-) battery terminal, through the LED, and back to the positive (+) terminal.

Now, you'll follow the path of direct current as it moves through a circuit. Look at the figure of a simple circuit, in which pieces of copper wire and a resistor are attached to an LED. The other ends of the wires are connected to the positive and negative terminals of a dry cell battery. Once the circuit is closed (that is, when all the wires are connected) the electrons will be free to move.

Recall that like charges repel and unlike charges attract. Since electrons have negative charges, they're *repelled* from the negative battery terminal and *attracted* to the positive terminal. The surplus of electrons leaves the negative terminal of the battery and enters the wire. These electrons move along and enter the resistor and LED. This explanation of how direct current moves is called *electron flow theory*.

The flow of electrons from the battery produces a useful result from our circuit, light. This light is created inside the LED as electrons are pushed across the two differently charged materials. One is known as an *N material*, with an excess number of electrons, while the other is called a *P material*. As you might expect, the P material lacks electrons. The electron movement within the LED is very similar to that found in the battery, except the charges in the LED are very, very

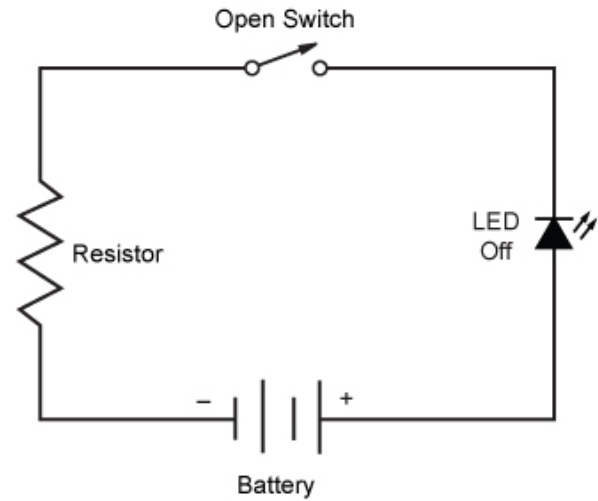
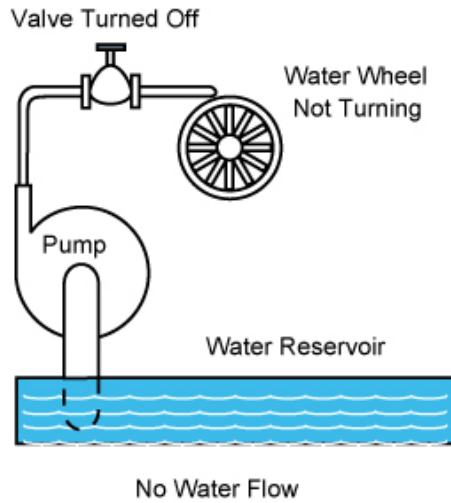
small. A boundary exists inside the LED to prevent the N and P materials from merging. However, once a certain voltage level is reached, electrons are pushed from the N to the P material, causing the LED to give off light. LEDs fail when exposed to too much voltage or current. That's why the circuit in the figure includes a resistor, which lowers the 3.0 volt battery output to about 1.7 volts before the charge flows to the LED. You'll soon learn more about the use of resistors in circuits.

Note that the battery in the figure is positioned with the positive terminal at the top, and the direction of electron flow is therefore counterclockwise. If the LED was reversed and the battery was turned upside down, the positive terminal would then be at the bottom, and the direction of electron flow would be clockwise. In either case, the current is direct—it flows in only one direction.

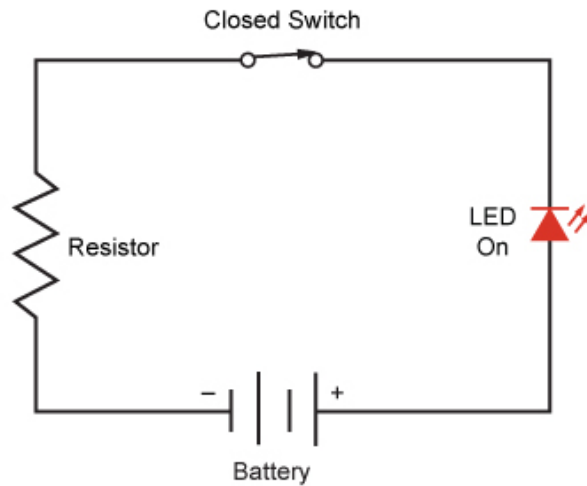
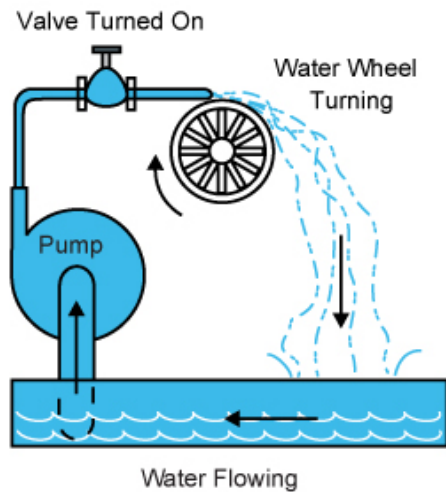
The direct current continues moving at a constant rate through the LED, keeping it lit. The battery keeps working until all of its chemicals are used up. At that point, a new battery will be required to keep the circuit working.

Comparing an Electrical System to a Water System

A good way to understand the flow of direct current is to compare an electrical system to a water system. In fact, the flow of electricity and the flow of water have many of the same properties.



Circuit Turned Off
(A)



Circuit Turned On
(B)

[An image of an illustration demonstrating the flow of water and the flow of electricity have many of the same properties]

The flow of electricity can be visualized easily if you compare a water system and an electric circuit.

In the figure, a DC electric circuit is compared to a simple water circuit. The valve in the water system can be compared to the switch in the electrical system since the valve controls the flow of water and the switch controls the flow of electricity. The water wheel is like the LED in the electrical system since the water wheel will turn when water flows over it and the LED will light when electricity flows through it. The water reservoir and pump in the water system can be compared to the battery in the electrical system; the reservoir and pump supply water to the water system, and the battery supplies power to the electrical system. The pipes in the water system can be compared to the conductors in the electrical system.

In part A of the figure, both the water circuit and the electrical circuit are turned off. Both the water valve and the switch are in the off positions, so no water or electricity flows. The water wheel doesn't turn and the LED doesn't light.

In part B of the figure, the water valve is turned on. Water is pumped out of the reservoir; the water current then flows through the pipe, turns the water wheel, and returns to the reservoir. In the electrical system, when the switch is turned on, electric current flows from the battery through the wires, lights the LED, and returns to the battery. The battery, which corresponds to the reservoir and pump in the water circuit, serves as a source of electrical pressure, or voltage.

Electromotive Force (EMF)

Current needs a “push” to get its flow started. In a battery, this push is

produced by the difference in charge at the two opposing terminals. The electrons' urge to flow from the negative terminal to the positive terminal will get a current started. Whenever a positive charge and a negative charge are positioned close to each other, electromotive force exists. *Electromotive force*, often abbreviated EMF, is a force that tends to move electricity.

The term *potential*, or the ability to generate current, is also used to describe EMF. That is, a battery has potential, as all you have to do is connect wires to the battery to give the electrons a path to flow on.

Voltage and Amperage

The strength of EMF or electrical potential is measured in units called *volts*. The more volts that are present, the greater the electrical potential will be. The voltage level of a dry cell battery will vary depending on how many surplus electrons there are at the negative terminal. A typical small dry cell battery has an EMF of 1.5 volts.

In our water system example, the water pressure can be compared to voltage. The greater the water pressure is in the system, the greater the flow of water will be through the pipes. Similarly, the greater the voltage in an electrical circuit, the greater the flow of electrons will be. Direct current is maintained by a constant or uninterrupted voltage.

The amount of electric current flowing through a circuit is called *amperage*. The amount of current is measured in units called *amperes* or *amps*. One ampere of current is equal to the charge of

6,240,000,000,000,000,000 electrons flowing past a given point in a circuit in one second. You can see that it takes many millions of electrons flowing in a circuit to perform useful work!

In our water system example, the amount of water flowing through a pipe can be compared to amperage. Water can flow more easily through the system if a large pipe is used instead of a small one. In the electrical system, resistance to the flowing electrons (the amperage) can be decreased by using thicker conducting wires. Therefore, high-current circuits will use larger (thicker) conductors, while low-current circuits will use smaller (thinner) conductors.

Key Points and Links

READING ASSIGNMENT

Key Points

- Direct current (DC) is the flow of electrons in one direction, maintained by constant or uninterrupted voltage.
- Alternating current (AC) is the flow of electrons first in one direction and then in the opposite direction.
- Whenever a positive charge and a negative charge are positioned close to each other, electromotive force (EMF) exists; it's a force that tends to move electricity.
- The strength of EMF or electrical potential is measured in volts; the more volts that are present, the greater the electrical potential will be.
- The amount of electric current flowing through a circuit is

amperage; it's measured in units called amperes or amps.

- When measuring electricity, the quantity of electrical charge is measured in coulombs.
- The magnitude of electrical resistance in a circuit is measured in ohms; resistance is the opposition that a circuit creates against the flow of electrical current.
- Watts are used to measure power, or the amount of useful work that can be done by a circuit.
- The units of ohm, ampere, and volt have a special relationship to one another as defined by Ohm's law.
- Ohm's law states that voltage (in volts) equals current (in amperes) multiplied by resistance (in ohms).

Exercise: Current Flow

Fill in the blanks.

1. The movement of electrons is called electric _____.
2. A common source of direct current is a/an _____.
3. If an LED is properly connected by wires to the terminals of a battery, electrons will leave the _____ terminal of the battery and flow through the wire toward the bulb.
4. In an electrical circuit, the conductors can be compared to the _____ in a water system.
5. In a water system, a valve can be compared to the _____ in an electrical system.

6. Another term for electromotive force is _____.

Exercise Answer Key:

Exercise: Current Flow

1. current
2. battery
3. negative
4. pipes
5. switch
6. potential

1.4 Describe common notations and prefixes used to identify electrical and electronic values

Electrical Units and Notations

READING ASSIGNMENT

32Electrical Units

Before going further with your study of electricity, it will be helpful to look at some of the standard units, notations, and symbols used in electrical work. In the fields of electricity and electronics, a variety of terms are used to describe quantities in electrical components and circuits. Some of these units are volts, amps, coulombs, ohms, and watts.

Electrical Units		
Quantity	Unit	Definition of Basic Unit
Potential	Volt (V)	One volt is the work of one joule per coulomb.
Current	Ampere (A)	One ampere is the movement of electrical charge at a rate of 1 coulomb per second.
Charge	Coulomb (C)	One coulomb is the quantity of charge equal to 6.24×10^{18} electrons.
Resistance	Ohm (Ω)	One ohm is the resistance which allows a current of one ampere when an electromotive force of one volt is applied to a conductor.
Power	Watt (W)	One watt is the power exerted in a circuit with an electromotive force of 1 volt and a current of 1 ampere.
Energy	Joule (J)	One joule is the energy dissipated as heat when one ampere passes through a resistance of one ohm for one second.

You've already learned about volts and amps. Remember that the strength of EMF, or electrical potential, is measured in volts, and the voltage in an electrical system can be compared to the water pressure in a water system. The stronger the voltage, the stronger the flow of electrons in an electrical circuit. Voltage is abbreviated most often as V , sometimes as E .

Amperage refers to the amount of electric current flowing through a circuit and is measured in amperes, or amps. The amount of water flowing through a pipe can be compared to amperage. Amperage is abbreviated A or I .

When measuring electricity, the quantity of electrical charge is

measured in *coulombs*. One coulomb is a charge that's equal to 6,240,000,000,000,000,000 electrons (these electrons are standing still, not flowing). The abbreviation for coulomb is *C*.

Electrical *resistance* is the opposition that a circuit creates against the flow of electrical current. The magnitude of electrical resistance in a circuit is measured in *ohms*. One ohm is equal to the resistance of a circuit in which one volt of EMF is applied to produce one ampere of current. The abbreviation used for ohm is the Greek symbol capital omega (Ω).

The use and measurement of resistance is very important in industry. You'll often rely on resistance measurements to judge if a circuit or component is working properly. For example, as you've learned, even copper wire offers a small amount of resistance to the flow of electrical current. Since an electric motor depends on a long length of copper wire wound into a coil shape, you can tell if a motor is in good electrical condition by measuring the resistance of its wire coil. A failed or *open* wire within the coil is indicated by a much higher resistance reading than a wire that isn't failed.

Another electrical unit you should be familiar with is the *watt*. Watts are used to measure *power*, or the amount of useful work that can be done by a circuit. The abbreviation for watt is *W*. You'll often encounter lighting and heating equipment rated in watts.

How Electrical Units Are Related

Three of the electrical units we just discussed have a special relationship to one another. These three units are the ohm, the ampere, and the volt. The mathematical connection between these units was first defined in the nineteenth century by the physicist Georg Ohm, and his statement of this relationship is called *Ohm's law*.

Ohm's law states that the voltage in an electrical circuit is equal to the current multiplied by the resistance. If we use the letters V , I , and R to represent voltage, current, and resistance, we can state Ohm's law with the following mathematical formula:

$$V = I \times R$$

In this formula, the letter V stands for voltage (in volts), the letter I stands for current (in amperes), and the letter R stands for resistance (in ohms).

In your work with electricity, Ohm's law will have many practical applications. Using the Ohm's law formula above and a little basic math, you can determine the voltage, current, or resistance in any circuit.

Scientific Notation

Frequently in electrical work, it's necessary to refer to very large and very small numbers. For example, in an earlier section of this text, you learned that one ampere is equal to the flow of 6,240,000,000,000,000 electrons past a given point in a circuit in

one second. This is a very large number, and it's difficult to speak about electrons in this way. Fortunately, there's an easier method we can use to express very large (or very small) numbers in simple terms. This method is called scientific notation.

Scientific notation is a method of abbreviating a number by writing the number as a simple multiplication problem. The multiplication problem consists of a whole number or a decimal multiplied by a power of ten. Read the table that lists the powers of ten. Note that 10 to the zero power (10^0) is always equal to 1.

Powers of Ten	
Greater Than Zero	Less Than Zero
$1 = 10^0$	
$10 = 10^1$	$1/10 = 10^{-1}$
$100 = 10^2$	$1/100 = 10^{-2}$
$1,000 = 10^3$	$1/1,000 = 10^{-3}$
$10,000 = 10^4$	$1/10,000 = 10^{-4}$
$100,000 = 10^5$	$1/100,000 = 10^{-5}$
$1,000,000 = 10^6$	$1/1,000,000 = 10^{-6}$

Using this knowledge, suppose you want to abbreviate the number 2,000,000. Instead of writing a 2 followed by all those zeros and

commas, you can abbreviate 2,000,000 like this:

$$2 \times 10^6$$

This multiplication expression is a shorter way to indicate the number 2,000,000. The number 2,000,000 is equal to 2 times 1,000,000. In the table, you find that 1^6 is equal to 1,000,000. The number 10^6 means “10 to the sixth power,” or 10 multiplied by itself six times ($10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1,000,000$). So, two multiplied by 10^6 is equal to 2,000,000.

Using scientific notation, you can change the very large number 6,240,000,000,000,000 (that is, the number of electrons moving in one ampere) to the much more simple 6.24×10^{18} .

The figure displays the wattage of a very large generator—2,300,000 watts. To convert this large number to scientific notation, you must first get rid of all the zeros at the end of the number. To do this, move the decimal point at the end of the number six places to the left, and place it between the 2 and the 3. After moving the decimal point, the number 2.3 remains. You moved the decimal point six (6) places to the left, so the power of ten you must use in the scientific notation is positive 6.

Therefore, 2,300,000 watts written in scientific notation is 2.3×10^6 watts.

Step 1: Start with the large number 2,300,000. The decimal point is located at the end of the number.

2 3 0 0 0 0 0 .
↑
decimal point

Step 2: Move the decimal point to the left six places, and place it between the 2 and the 3, as indicated by the arrows.

2 3 0 0 0 0 0 .
↑↑↑↑↑↑

Step 3: Write the number 2.3 followed by a times sign.

2.3 ×

Step 4: We moved the decimal point six places to the left, so the power of ten in this expression will be 10^6 .

2.3 × 10^6

[An image of the process of converting a large number to a simpler version expressed in scientific notation]

This figure demonstrates how to convert a large number to a simpler version of the number expressed in scientific notation.

Now, look at a very small number. The figure shows the time period 0.0000025 second, the amount of time for a very short signal on a circuit board. To convert this number to scientific notation, you must first get rid of all of the zeros at the beginning of the number. To do this, you'll need to move the decimal point six places to the right, and place it between the 2 and the 5. After moving the decimal point, the number 2.5 remains. You moved the decimal point six (6) places to the right, so the power of ten you must use in the scientific notation is negative 6. So, 0.0000025 second written in scientific notation is 2.5×10^{-6} second.

Step 1: Start with the number 0.0000025. The decimal point is located at the front of the number.

0.0000025
↑
decimal point

Step 2: Move the decimal point to the right six places, and place it between the 2 and the 5, as indicated by the arrows.

0.0000025
↑↑↑↑↑↑

Step 3: Write the number 2.5 followed by a times sign.

2.5 ×

Step 4: We moved the decimal point six places to the right, so the power of ten in this expression will be 10^{-6} .

2.5×10^{-6}

[An image of the process of converting a small number with many zeros to a simpler version expressed in scientific notation]

This figure demonstrates how to convert a very small number with many zeros to a simpler version of the number expressed in scientific notation.

Prefixes

When electrical units are shown in writing, it's often necessary to indicate very large or very small numbers of watts, volts, ohms, and so on. Using scientific notation makes the numbers easier to handle, but they can still be bulky to use in calculations. For this reason, you'll often see prefixes attached to these electrical units. *Prefixes* are short word parts that are attached to the beginnings of words. In science, prefixes are often used to indicate a number.

A list of standard electrical prefixes is shown in the table. Any of these

prefixes may be used with electrical terms to indicate very large and very small numbers. Be sure to study these prefixes carefully so that you're familiar with them.

Standard Electrical Prefixes			
Value	Prefix	Symbol	Example
1,000,000,000 = 1^9	<i>giga-</i>	G	GW = gigawatt (one billion watts)
1,000,000 = 1^6	<i>mega-</i>	M	MW = megawatt (one million watts)
1,000 = 1^3	<i>kilo-</i>	k	kΩ = kilohm (1,000 ohms)
0.001 = 10^{-3} "one thousandth"	<i>milli-</i>	m	mV = millivolt (0.001 volt)
0.000001 = 10^{-6} "one millionth"	<i>micro</i>	μ	μF = microfarad (10^{-6} farad)
0.000000001 = 10^{-9} "one billionth"	<i>nano-</i>	n	ns = nanosecond (10^{-9} second)
0.000000000001 = 10^{-12} "one trillionth"	<i>pico-</i>	p	pC = picocoulomb (10^{-12} coulomb)

Giga- is the first prefix in the table, and it means "one billion." If you place the prefix *giga-* in front of the term *watt*, you create a new term, *gigawatt*. One gigawatt is equal to one billion watts. This word may be used when talking about the output of a large power plant.

The next prefix is *mega*, which means "one million." If you place the prefix *mega* in front of the term *watt*, you create the term *megawatt*. One megawatt is equal to one million watts. The output of a large

electrical generator at a utility company is commonly measured in megawatts. Or, you may hear that a large commercial building or factory consumes several megawatts of electrical power.

The prefix *milli-* is another example. The prefix *milli-* can be placed in front of the term *volt* to create a new term, *millivolt*. The prefix *milli-* means “one thousandth,” so this tells you that one millivolt is equal to one-thousandth of one volt.

From the examples of converting to scientific notation earlier, you can now simplify 2.3×10^6 watts to 2.3 megawatts, and 2.5×10^{-6} second to 2.5 microseconds.

When dealing with either prefixes or scientific notation, always double-check the units in your calculations to make sure they're consistent. There's a very big difference between 2.3 watts and 2.3 megawatts!

Key Points and Links

READING ASSIGNMENT

Key Points

- Prefixes are often attached to electrical units to indicate very large or very small numbers of watts, ohms, and so on; the table below lists standard prefixes.
- Standard Electrical Prefixes:

Prefix	Meaning	Symbol
giga	one billion	G

mega	one million	M
kilo	one thousand	k
milli	one thousandth	m
micro	one millionth	μ
nano	one billionth	Π
pico	one trillionth	ρ

- Scientific notation is a method used to refer to very large and very small numbers; the number is written as a simple multiplication problem with a whole number or decimal multiplied by a power of ten.

Greater than Zero	Less than Zero
$1 = 10^0$	
$10 = 10^1$	$1/10 = 10^{-1}$
$100 = 10^2$	$1/100 = 10^{-2}$
$1,000 = 10^3$	$1/1,000 = 10^{-3}$
$10,000 = 10^4$	$1/10,000 = 10^{-4}$
$100,000 = 10^5$	$1/100,000 = 10^{-5}$
$1,000,000 = 10^6$	$1/1,000,000 = 10^{-6}$

- As an example, 2,000,000 can be written as 2×10^6 .
- The scientific notation used is based on the number of places is

moved to the right (positive) or to the left (negative).

Exercise: Abbreviations and Notations

Match the electrical units in Column I with their symbol in Column II.

Column I	Column II
1. volt	a. Ω
2. ampere	b. C
3. ohm	c. W
4. coulomb	d. V
5. watt	e. I

Respond to the following based on your reading.

- Convert the number 43,000 to scientific notation.
- Convert the number 0.0025 to scientific notation.
- What prefix is used to indicate the number 1,000,000?
- What number does the prefix *nano* stand for?

10. What prefix is used to indicate the number 0.000001?

Exercise Answer Key:

Exercise: Abbreviations and Notations

1. d
2. e
3. a
4. b
5. c
6. 4.3×10^4
7. 2.5×10^{-3}
8. mega
9. 0.000000001
10. micro

1.5 Define carbon resistors, potentiometers, rheostats, and relays and how they work

Resistance

READING ASSIGNMENT

As you've learned, *resistance* is the opposition that a circuit or substance creates against the flow of electrical current. Referring to the previously used water system comparison, you can compare

resistance to the diameter of the pipe. The narrower the pipe, the less water that can flow through the pipe. The only way to get more water to flow through a narrow pipe would be to increase the water pressure. In the same way, a very thin wire offers more resistance to the flow of electricity than does a thick wire. The only way to increase the flow of electricity in a thin wire would be to apply more voltage to it.

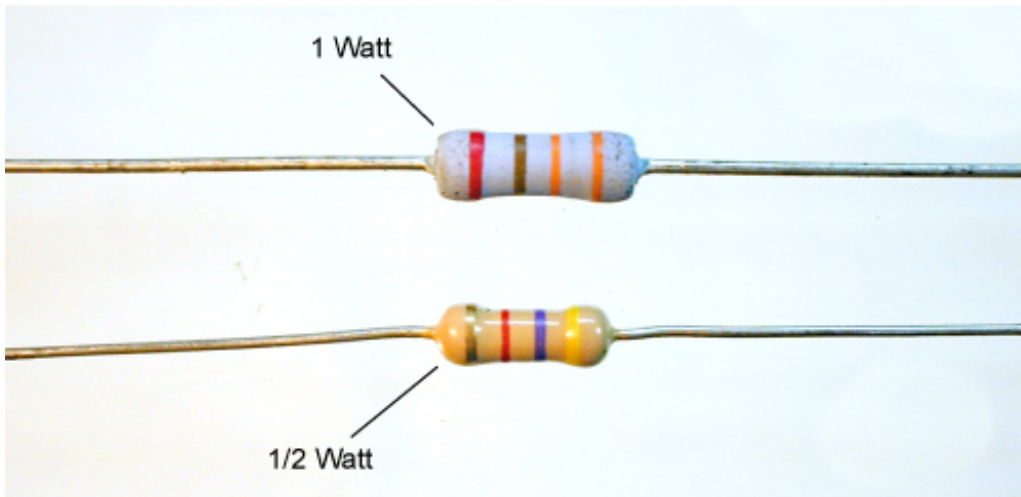
Every electrical circuit contains at least some resistance. This is because no substance is a perfect conductor. For example, silver metal is an excellent conductor, but it's not perfect—it will always put up some resistance to the flow of electricity through it.

The magnitude of electrical resistance in a circuit is measured in *ohms*. One ohm is equal to the resistance of a circuit in which one volt of EMF is applied to produce one ampere of current. The abbreviation for the ohm is the Greek symbol *omega*, Ω .

Fixed Resistors

You've seen how some materials resist electrical flow. Now, you'll examine how resistive materials can be used to make resistors.

Resistors are devices that resist or oppose the flow of electrons through a circuit. Resistors are commonly used to protect circuits and control the flow of electricity through them. However, a resistor doesn't completely prevent the flow of electricity. This principle has many practical applications in industry.

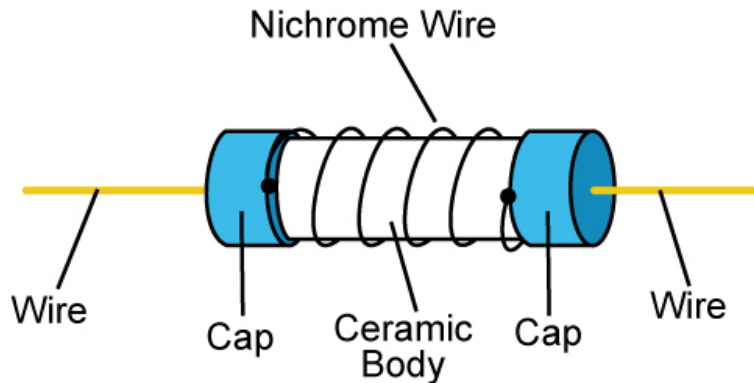


[An image of typical carbon resistors]

These are typical carbon resistors.

The most common type of resistor is the *carbon resistor*, also called a *fixed resistor*. A carbon resistor has a body made of resistive carbon surrounded by a composite sealing material. A stiff wire lead protrudes out of each end of the resistor. A series of colored bands mark the resistor. The color bands identify the resistor's value as measured in ohms.

Most carbon resistors tend to have a very high resistance to electrical current. While a carbon resistor may have a value as small as one-tenth of an ohm, values in the hundreds, thousands, or even millions of ohms are more common. Carbon resistors are used in electronic circuits either to control the flow of current or to lower the voltage delivered to an electronic device (such as an integrated circuit).



[An image of a wire-wound resistor]

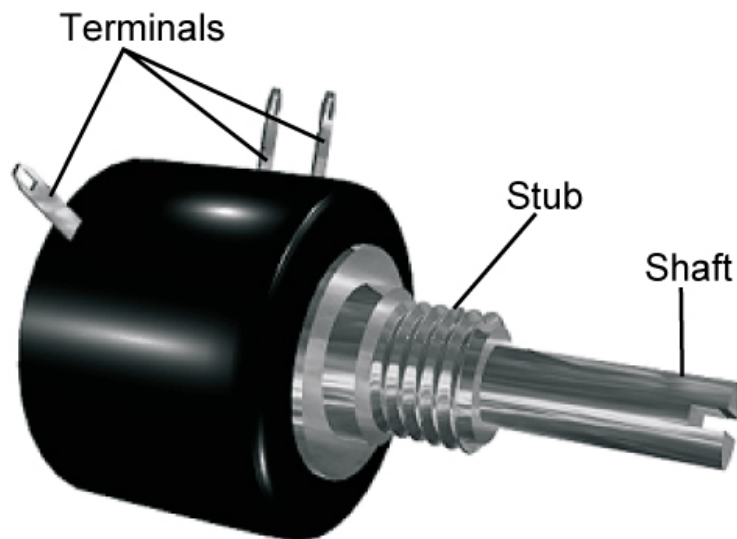
A wire-wound resistor is shown here. These resistors are often used in high-power circuits, like those found in heaters and DC motor controls.

Another type of resistor is the *wirewound resistor*. A wirewound resistor consists of a porcelain or ceramic tube that's wrapped with a length of wire. *Nichrome*, a type of wire that's a poor conductor, is often used.

Wirewound resistors generally have lower resistance values than carbon resistors. Typical wirewound resistors have resistance values of tens, hundreds, or thousands of ohms. The resistance value is largely determined by the length and thickness of the wire used in the resistor, and how well the wire conducts electricity. These resistors are often used in the high-power circuits found in heaters and DC motor controls.

Variable Resistors

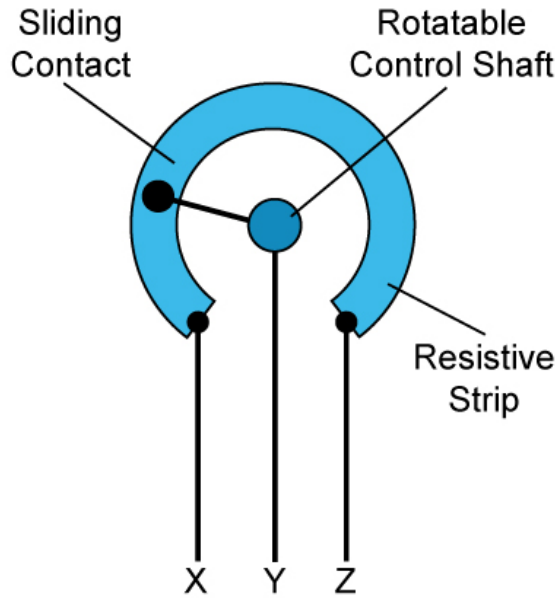
Carbon resistors and wirewound resistors have fixed resistance values. That is, they provide an unchanging resistance to the current in a circuit. However, there's one type of resistor that can change its resistance: the *variable resistor*.



[An image of the main external parts of a potentiometer]

This figure shows the main external parts of a potentiometer. Note the three terminals that are used to make electrical connections to the potentiometer.

A *variable resistor*, often called a *potentiometer*, is normally used as a control device to adjust an electronic circuit. Potentiometers are used when varying control of the resistance in a circuit is needed.



[An image of a simplified drawing of the structure of a potentiometer]

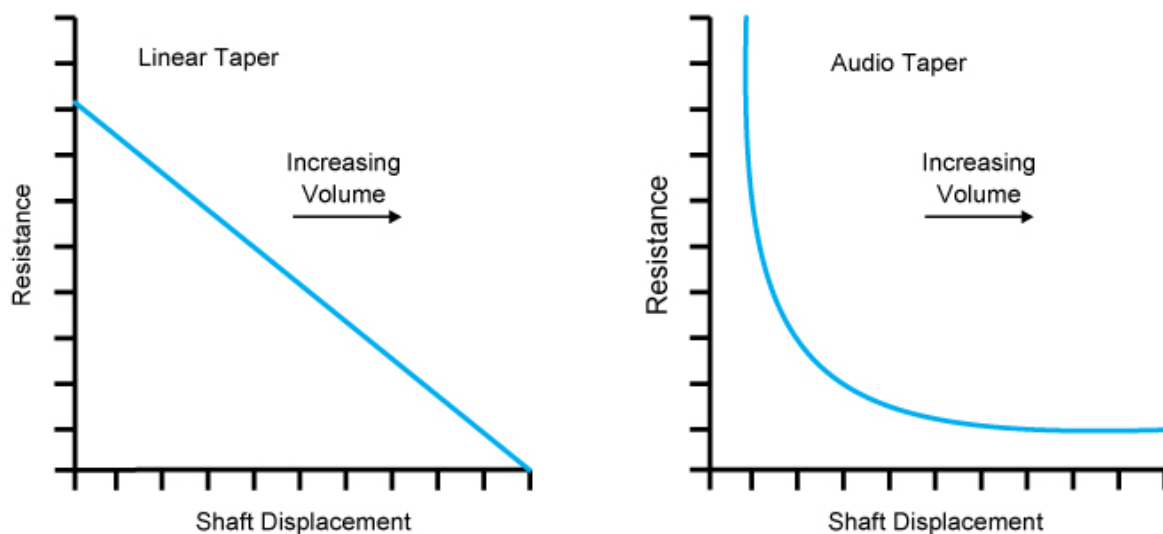
The major parts of a potentiometer include a resistive strip, a sliding contact, and a rotating shaft.

A simplified drawing of the structure of a potentiometer is shown in the figure. Note that a potentiometer contains a resistive strip bent almost into a circle, with terminals connected to either end. The resistive strip is generally made of a carbon composition. A sliding contact called a *wiper* is attached to a rotating control shaft. The wiper is made of a copper material that slides along the surface of the resistive strip to vary the resistance.

There are two basic types of potentiometers, the linear taper and the audio taper. In a *linear taper*, each increment of shaft rotation

corresponds to an equal amount of resistance change. In an *audio taper*, the resistance varies greatly according to the amount of shaft rotation, especially at the clockwise extreme of shaft rotation. Audio taper potentiometers are often used as volume controls on portable radios. This is because the rotation of the audio taper potentiometer provides a smoother adjustment of the volume level.

The figure compares the actions of a linear taper and audio taper. In the figure, both potentiometers are used for volume control. The linear taper increases the sound very quickly, while the audio taper increases the sound by much more gradual increments.



[An image of an illustration comparing a linear taper and audio taper when used for volume control. The linear taper increases the sound very quickly, while the audio taper increases the sound in more gradual increments]

This illustration shows you how an audio taper and a linear taper potentiometer compare in performance when used as volume controls.



(A)



(B)

[An image of miniature potentiometers, whose resistance can be adjusted by turning the small adjusting screw]

You can change the resistance of a circuit board potentiometer like these by turning its

adjusting screw clockwise or counterclockwise.

Miniature potentiometers are used on circuit boards for temperature, lighting, and motor control circuits. The resistance of the miniature potentiometers shown in the figure can be adjusted by turning the small adjusting screw.

A special type of potentiometer called a *rheostat* is used in some high-power circuits. Rheostats may have a diameter of one to eight inches, so they're larger than ordinary potentiometers. A rheostat's resistance element is usually made of resistance wire wound around a ceramic core. Rheostats can conduct greater currents than potentiometers. Rheostats are often used in motor, generator, or alternator circuits for speed or voltage control.

A rheostat is similar in construction to a potentiometer, but it's much larger. A wiper slides across the resistance wires to vary the resistance. Some high-current rheostats use a carbon brush on the end of the wiper to contact the resistance wires.

The final type of variable resistor we'll examine is the *slide potentiometer*. A slide potentiometer is a wirewound resistor with a sliding tap. The resistance of this device can be varied by loosening the clamping screws and sliding the tap to a new location. This type of resistor is used in power circuits where resistance changes will be made infrequently.

Always remove the power from a circuit before adjusting a slide potentiometer. Since the tap is under power in the circuit, there's a very serious shock hazard.

Resistor Symbols and Ratings



Fixed Resistor

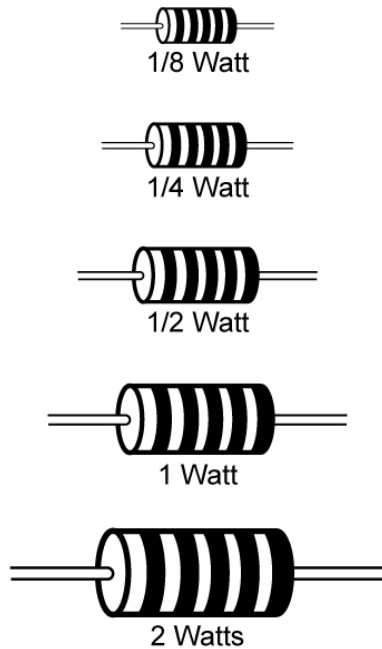


Variable Resistor

[An image of the symbols used for fixed and variable resistors]

Shown here are the symbols used for fixed and variable resistors.

There are two basic symbols used to indicate resistors in electrical or electronic circuit diagrams. The resistor symbol is a simple “zigzag” line. The variable resistor symbol includes a small arrow to represent the wiper. In a circuit diagram, to indicate that the resistance is lowered, the small arrow is moved to the left side of the resistor symbol.



[An image of typical sizes of carbon resistors]

Here are the various sizes of typical carbon resistors based on the wattage they can safely handle.

Resistors are rated in two ways: according to their resistance values (in ohms) and according to the amount of power they can handle (in watts). Remember that the symbol for ohms is Ω , so a resistor that has a resistance of 100 ohms will be labeled 100 Ω . If the resistor value reaches into the thousands of ohms, the prefix *k* (meaning 1,000) is used before the ohm symbol. So, a 5,000-ohm resistor will be labeled 5 k Ω . Finally, to indicate millions of ohms the prefix *M* is used before the ohm symbol. So, a 10,000,000-ohm resistor will be

labeled 10 MΩ (ten *megohms*).

As mentioned, resistors are also rated according to the amount of power they can handle in watts. The amount of power that's actually handled by the resistor is the product of the voltage across the resistor and the current flowing through the resistor. This relationship is expressed with the formula $Power = V \times I$.

Resistor Color Codes

You may remember that a carbon resistor will have color bands surrounding the resistor. These color bands can be decoded easily to determine the resistance value of a resistor, in ohms. Read the Resistor Color Codes table. The color bands on the resistor are “read” from left to right.

RESISTOR COLOR CODES Start with the Bands on the Left-Hand End					
Color	Band 1	Band 2	Band 3		Band 4*
	First Digit	Second Digit	Number of Zeros		Tolerance
Black	0	0	none		none
Brown	1	1	one	0	±1%
Red	2	2	two	00	±2%
Orange	3	3	three	000	
Yellow	4	4	four	0,000	

Green	5	5	five	00,000	±0.5%
Blue	6	6	six	000,000	±0.25%
Violet (Pink)	7	7	seven	0,000,000	±0.1%
Gray	8	8	eight	00,000,000	±0.05%
White	9	9	nine	000,000,000	
Gold			multiplier 0.1		±5%
Silver			multiplier 0.01		±10%
* No fourth band means 20% tolerance.					



[An image of a chart showing resistor color codes]

This chart can be used to decode the value of any carbon resistor.

To decode the bands in a resistor, first look at the band on the far left-hand end of the resistor. The color of this band will tell you the first digit in the resistor's value. Determine the color of the band, find that color on the chart, and read across to find the first digit. So, if the color of the leftmost band on the resistor is white, the first digit of the resistor value would be 9.

Next, move to the second color band. The color of this band will tell you the second digit in the resistor value. So, for example, if the second band from the left is blue, the second digit in the resistor value will be 6.

The color of the third band will tell you how many zeros are placed after the first two digits in the resistor's value. So, if the resistor's third band is white, you'll place nine zeros after the first two digits.

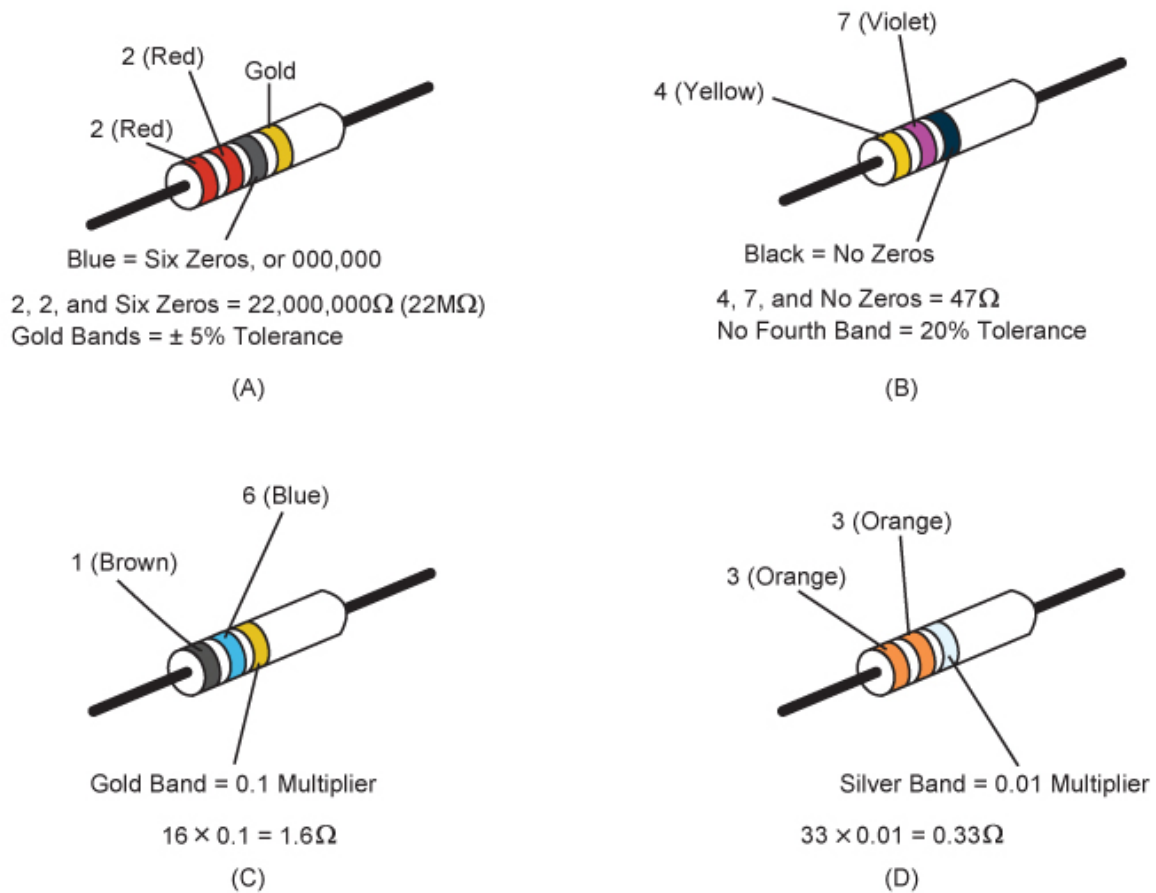
Note that if a resistor has a third band that's gold or silver, it will have a multiplier instead of a number of zeros. To find the resistance value, simply multiply the first two digits by the multiplier given in the chart.

The fourth band on a carbon resistor tells you the tolerance of the resistor (stated as a percentage). The *tolerance* is the allowable amount of difference between the true resistance and the labeled resistance. The true resistance provided by a resistor may actually be slightly greater than or less than its labeled resistance.

So, if a carbon resistor has a labeled resistance of 33 MΩ and a tolerance of 5 percent, you must multiply 0.05 times 33×10^6 to get 1.65×10^6 . This means that the true resistance of the resistor may be 1.65 MΩ greater than or less than the labeled resistance of 33 MΩ. If no fourth band is present on the resistor, the tolerance is assumed to be 20 percent.

The figure shows four resistors with their color bands decoded. You'll begin by decoding the resistor shown in A. This resistor has color

bands of red, red, blue, and gold (reading from left to right). According to the chart in the previous figure, these color bands will convert to the digits 2, 2, and six zeros, which equals 22,000,000 Ω , or 22 M Ω . The gold fourth band means that the resistor has a tolerance of 5 percent.



[An image of four resistors with their color bands decoded]

These examples show how the colored bands on resistors represent resistance values.

The tolerance of 5 percent of 22 M Ω is equal to 1.1 M Ω (multiply 0.05 times 22×10^6). This means that the true resistance of this resistor could be 1.1 M Ω higher or 1.1 M Ω lower than the labeled resistance of

22 M Ω . Therefore, the true resistance of the resistor may be as low as 20.9 M Ω ($22 \text{ M}\Omega - 1.1 \text{ M}\Omega = 20.9 \text{ M}\Omega$), or it may be as high as 23.1 M Ω ($22 \text{ M}\Omega + 1.1 \text{ M}\Omega = 23.1 \text{ M}\Omega$).

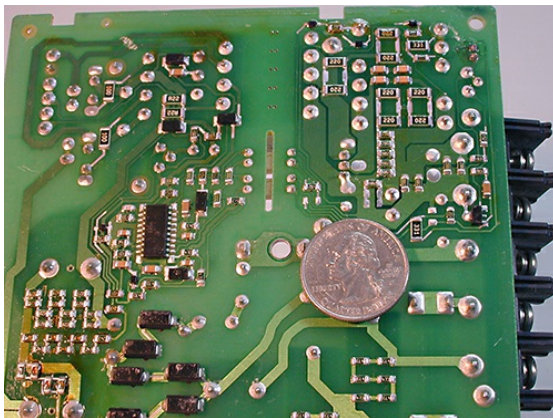
Another example is the resistor shown in part B of the figure. It has three color bands: yellow, violet, and black (reading from left to right). These color bands convert to the digits 4, 7, and no zeros. The resistance value is therefore 47 Ω . Also, according to the Resistor Color Codes table, since there's no fourth band, the tolerance is assumed to be 20 percent (that is, 20 percent of 47 Ω). The resistor will, therefore, have a tolerance of $\pm 9.4 \Omega$ ($0.20 \times 47 \Omega = \pm 9.4 \Omega$). This means that the true resistance of this resistor could be either 9.4 Ω higher than or 9.4 Ω lower than the labeled resistance of 47 Ω . Therefore, the true resistance of the resistor may be as low as 37.6 Ω ($47 \Omega - 9.4 \Omega = 37.6 \Omega$), or it may be as high as 56.4 Ω ($47 \Omega + 9.4 \Omega = 56.4 \Omega$).

Resistors with resistance values of less than 10 Ω may have a gold- or silver-colored third band. If the third band is gold, the number represented by the first two bands should be multiplied by a value of 0.1. If the third band is silver, the number represented by the first two bands should be multiplied by a value of 0.01. These multiplier values are shown in the previous figure.

Now, look at the resistor shown in part C of the figure. This resistor has color bands of brown, blue, and gold (reading from left to right). These color bands convert to the digits 1 and 6, and the gold third

band indicates a multiplier of 0.1. This resistor will have a resistance of 1.6Ω ($16 \times 0.1 = 1.6$). The resistor has no fourth band, so the tolerance will be 20 percent.

The resistor in D has color bands of orange, orange, and silver. These color bands convert to the digits 3 and 3, and the silver third band indicates a multiplier of 0.01. This resistor will have a resistance of 0.33Ω ($33 \times 0.01 = 0.33$). The resistor has no fourth band, so the tolerance will be 20 percent.

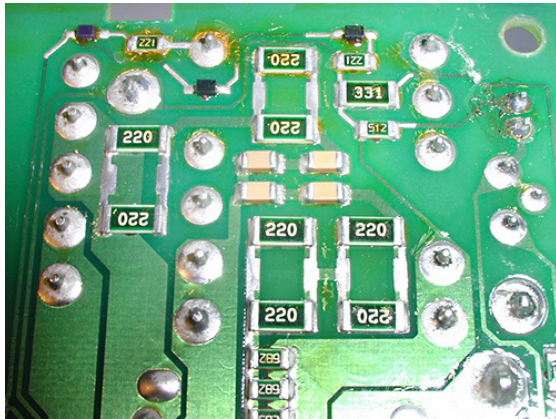


[An image of a circuit board containing multiple SMD resistors]

This circuit board contains many SMD devices. The use of these devices helps shrink the size of modern circuit boards compared to older circuit boards built from standard-sized components.

A common form of resistor found on modern circuit boards is the

surface mount device, or SMD resistor. SMD resistors look like very small rectangles with a small tab at each end. On this board are many very small resistors along with other electronic components. Because of their small size, their wattage rating is quite low, meaning they can't be exposed to high levels of electrical load.



[An image of a group of SMD resistors]

Here is a closer look at a group of SMD resistors.

Look now at the closer view of the SMD resistors and other electronic components. Note how little space is required between components. Because they're so small, there's no room to print color bands on SMD resistors. Instead, they're identified with a number code. For example, an SMD resistor with 103 printed on its case would have a resistance equal to the first two digits on their label (in this case, 10), followed by the number of zeros identified by the third digit on the label (in this case, 3). This means the SMD would offer 10,000 Ω , or 10 k Ω , of resistance.

A potentiometer's resistance is often marked on the rear or side of its body. You'll often see a series of manufacturing code numbers that specify the model of potentiometer along with a resistance number (such as 10 k Ω , indicating a ten-thousand-ohm potentiometer). This resistance is measured between the X and Z terminals of the potentiometer shown in the figure.

Wirewound rheostats and resistors are marked in the same way as potentiometers. For example, a wirewound resistor that's marked 5 k Ω , 200 W indicates a 5,000-ohm, 200-watt resistor.

Any type of resistor, potentiometer, or rheostat can be measured with a meter to find its resistance value. However, the resistor must be removed from the circuit to perform this measurement properly.

Industrial Applications of Resistance

Resistance has many practical applications in industry. For example, resistant wire coils are used in a variety of heating devices such as ovens, kilns, and soldering irons. As a residential electrician, you'd most likely see resistant wire coils in electric hot water heaters. These heating coils are made of a special resistance wire that's coiled and enclosed in an insulating powder and metal shell.

Some types of resistors, often used as temperature sensors, offer a different amount of resistance to the flow of electrical current depending on their temperature. Other types can change resistance based on pressure. These resistors are found in devices known as

strain gauges, which measure force or weight. You'll also find resistors used with other electronic components in many types of timing circuits. However, the most common use of resistors is to simply limit the voltage and current in a circuit.

Key Points and Links

READING ASSIGNMENT

Key Points

- Resistors are devices that resist or oppose the flow of electrons through a circuit, commonly used to protect circuits and control the flow of electricity through them.
- The carbon resistor is the most common type of resistor; it has a body made of resistive carbon surrounded by a composite sealing material and a stiff wire protruding from each end.
- Carbon resistors tend to have a very high resistance to electrical current and are used in electronic circuits to control the flow of current or to lower the voltage delivered to an electronic device.
- A potentiometer, or variable resistor, is typically used as a control device to adjust an electronic circuit.
- Potentiometers are used when varying control of the resistance in a circuit is needed.
- A potentiometer has a resistive strip that is bent almost into a circle, and a sliding contact, or wiper, that's attached to a rotating control shaft.
- The wiper slides along the surface of the resistive strip to vary

the resistance.

- In the linear taper type of potentiometer, each increment of shaft rotation corresponds to an equal amount of resistance change.
- In the audio taper type of potentiometer, the resistance varies greatly according to the amount of shaft rotation; they're often used as volume controls on portable radios.
- A rheostat is a special type of potentiometer that is used in some high-power circuits.
- A rheostat's resistance element is usually made of resistance wire wound around a ceramic core, and they can conduct greater currents than potentiometers.
- A relay is a type of electrical switch that works through electromagnetism.
- A relay contains a metal pole surrounded by a coil of wire and a small lever positioned between two sets of contacts; current flow controls the lever touching the contact points.

Exercise: Resistance in Circuits

Fill in the blanks

1. _____ is the opposition that a circuit or substance creates against the flow of electrical current.
2. A/An _____ is a wirewound resistor with a sliding tap.
3. Carbon resistors are also called _____ resistors.
4. A/An _____ is also called a variable resistor.

5. There are two basic types of potentiometers, the audio taper and the _____.
6. The fourth band on a carbon resistor tells you the _____ of the resistor (stated as a percentage).
7. _____, a type of wire with poor conductivity, is often used to make wirewound resistors.
8. If the fourth color band on a resistor is red, the resistor has a tolerance of _____ percent.

Exercise Answer Key:

Exercise: Resistance in Circuits

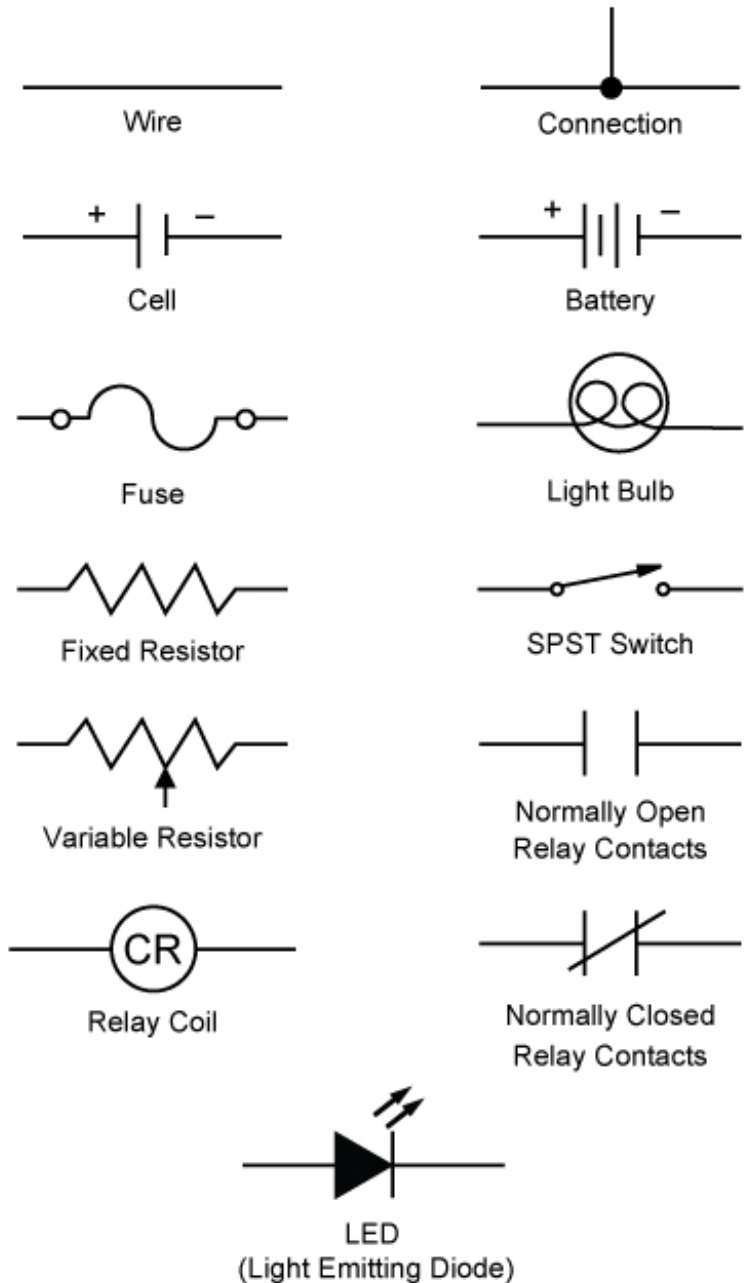
1. Resistance
2. slide potentiometer
3. fixed
4. potentiometer
5. linear taper
6. tolerance
7. Nichrome
8. two

1.6 Identify electrical symbols used in schematic diagrams and the difference between a series and a parallel circuit

Simple DC Circuits

READING ASSIGNMENT

34Circuit Drawings



[An image of standard symbols used to indicate electrical components in schematic diagrams]

Here are some of the standard symbols used to indicate electrical components in schematic diagrams.

To examine and compare several types of circuits, you'll need to examine a number of schematic diagrams. *Schematic diagrams* (or simply, "schematics") are simplified drawings of electrical circuits that show all the electrical components of a circuit including the power source, conductors, loads, switches, resistors, and so on.

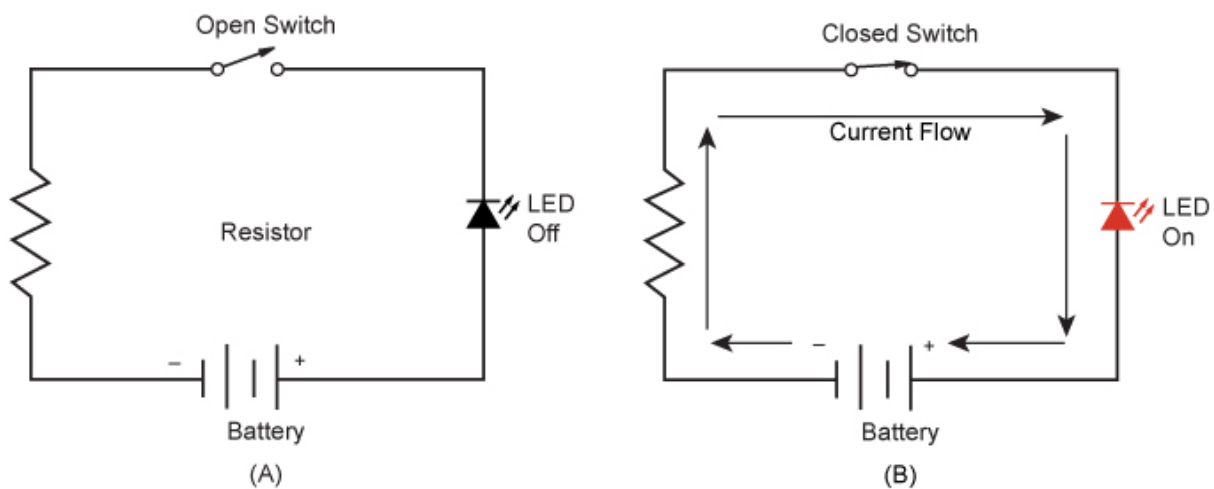
In your study of electricity and in actual electrical work, schematic diagrams are very important. All electrical or electronic components are identified on schematic diagrams by standard symbols. You should try to memorize these symbols so that you can recognize them whenever you see them.

Closed and Open Circuits

You learned earlier that a circuit is an electrical current path. A typical circuit includes a power source, conductors, a load, and a switch. When a switch is turned off, the circuit is broken; current can't flow through the wires to reach the load. This is called an *open circuit*. An open circuit can also occur accidentally as a result of a faulty electrical contact, a broken conductor, or a failed component.

In contrast, when the switch is turned on, current can flow on an unbroken path to the load. This is known as a *closed circuit* because the circuit is complete.

Now you'll review some of the concepts you learned about circuits. This schematic diagram shows the flashlight circuit you looked at earlier in this lesson. In part A, the switch is open, and no current can flow in the circuit. In part B, the switch has been turned on. Current flows from the negative terminal of the battery through the conductor, resistor, and switch, through the LED (lighting it), and then back to the positive battery terminal.



[An image of a diagram of an open flashlight circuit where the LED is off and a closed flashlight circuit where the LED is on]

This diagram shows a simple flashlight circuit. In (A), the switch is open and the LED is off. In (B), the switch is closed and current flows in the circuit.

The switch shown in the figure is a *single-pole, single-throw switch*, also called an *SPST switch*. The term “single-pole” means that the switch has only one contact inside the switch. The term “single-throw” means that the switch has only two positions: on or off.

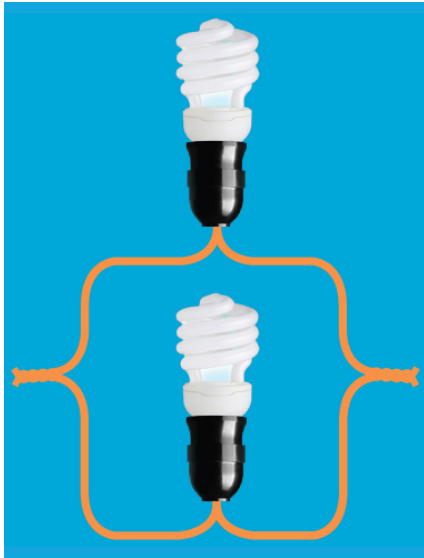
Series and Parallel Circuits

Electrical components can be connected together in two basic ways: in series or in parallel. In both types of circuits, several electrical components are connected together. In a *series circuit*, the current has only one electrical path to follow. The current flows through each of the components, one after another, in a straight line, and remains the same through all of the series components.



[An image of four light bulbs connected in a series arrangement; if one is removed, the others will fail to light]

These light bulbs are connected in series.



[An image of two light bulbs connected in a parallel arrangement; if one is removed, the other will continue working]

In this circuit, the two light bulbs are connected in a parallel configuration. If one of the bulbs is removed, the other will keep on working.

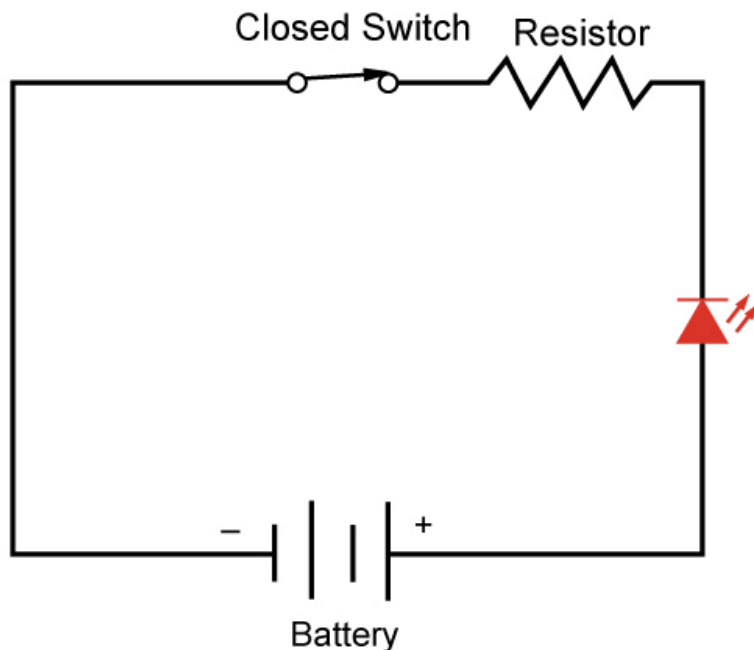
In contrast, in a *parallel circuit*, the current has two or more electrical paths to follow. The electrons flow from the negative battery terminal, branch out into the two or more electrical paths, flow through all the components in the circuit, and return to the positive battery terminal. The current “splits” among the parallel components, and adds together

to form the total current flowing through the parallel combination.

Look at the figure of the three light bulbs connected in a series arrangement. When a string of lights is connected in a series arrangement, if one light bulb is removed or burns out, the entire string will fail to light.

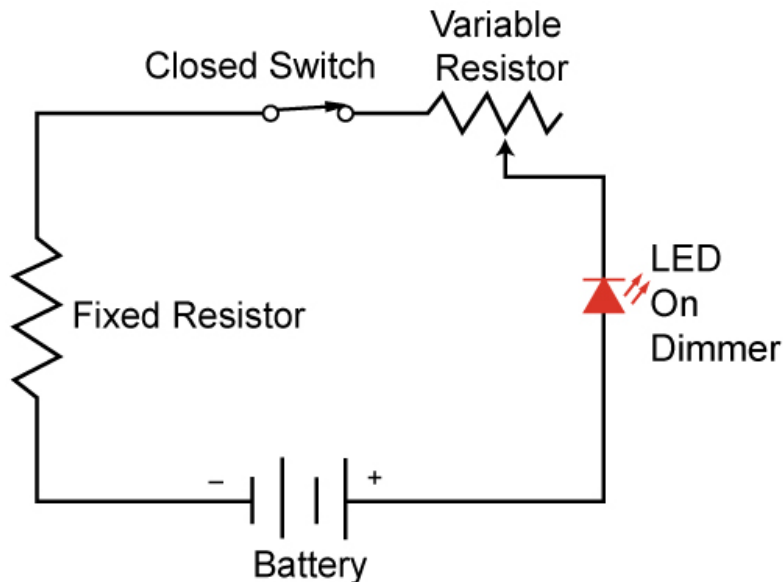
Now, look at the figure of two light bulbs connected in a parallel arrangement. When light bulbs are connected in a parallel arrangement, if one light bulb is removed or burns out, the remaining bulbs in the string will still light.

Resistors in Circuits



[An image of a series circuit containing a resistor between the switch and LED to lower the voltage applied to the LED]

This series circuit contains a resistor between the switch and the LED. This resistor will lower the voltage applied to the LED and limit the current in the circuit.



[An image of a series circuit containing a variable resistor between the switch and LED]

A variable resistor or potentiometer has been added to this series circuit. The wiper is represented by the small arrow below the resistor symbol. As the resistor's wiper is moved to the left, the LED brightens. As the wiper is moved to the right, the LED dims.

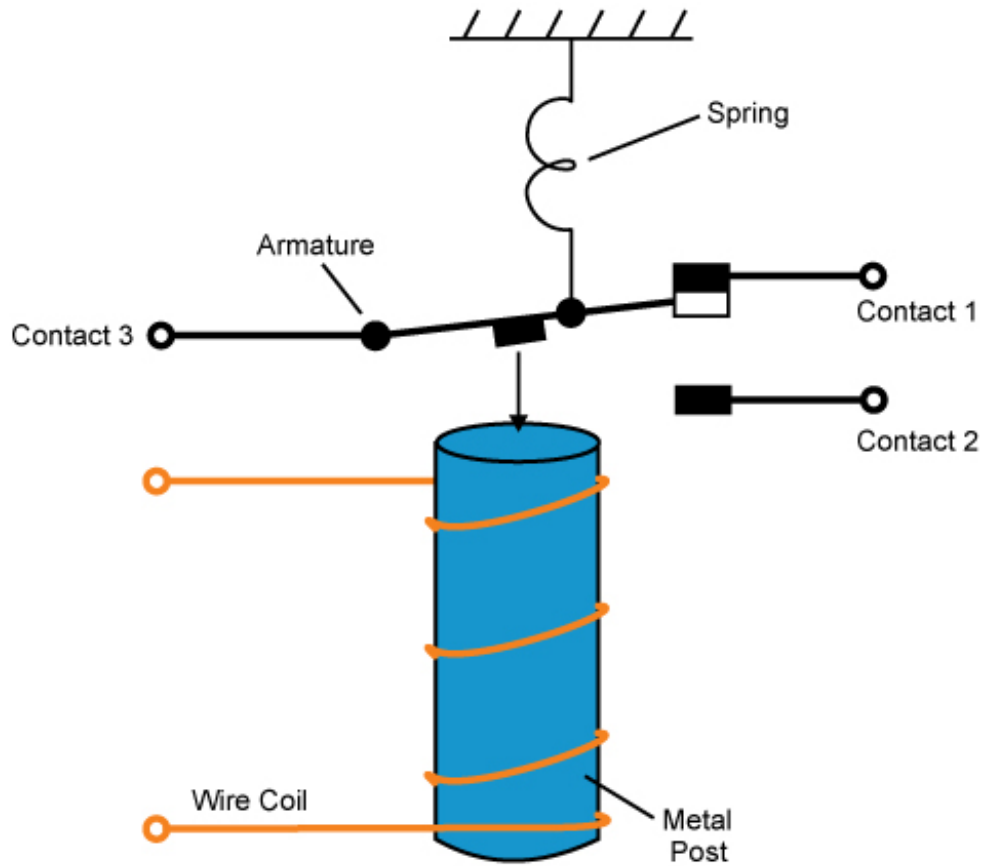
Recall discussion earlier in this lesson about resistors. A resistor can be entered into a circuit to lower the voltage and current supplied to the LED, allowing it to produce a maximum amount of light without failing due to voltage overload. The value of the resistor depends

upon the type of LED used and its maximum-voltage rating. A typical red LED requires 1.7 volts to begin to produce light. If placed in a circuit with a higher voltage than its maximum rating, the LED quickly heats up and fails.

A variable potentiometer can also be added to the circuit along with the fixed resistor. The fixed resistor keeps the LED from receiving too much voltage and current in the event the potentiometer is adjusted to a point where it offers little or no resistance. As the potentiometer is turned so that the arrow in the figure moves to the right, the resistance in the circuit increases. The voltage across the LED decreases and the LED dims. Increasing the resistance until the voltage across the LED is less than 1.7 volts causes the LED to stop producing light.

Relay Circuits

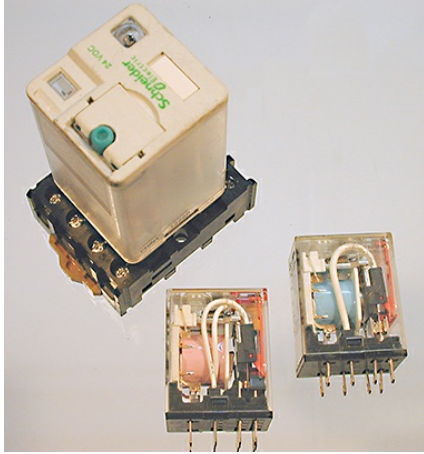
A *relay* is a type of electrical switch that works through electromagnetism. A relay contains a metal pole or post surrounded by a coil of wire. A small lever called an *armature* is positioned above the relay. One end of the armature is positioned between two sets of contacts. The distance between the contacts is large enough so that the armature can touch only one contact at a time. When no current flows through the coiled wire, the spring pulls the armature up until it touches Contact 1. A closed circuit now exists between Contact 1 and Contact 3 (the armature). An open circuit exists between Contact 2 and Contact 3.



[An image of a simplified drawing of a relay]

This illustration shows a simplified drawing of a relay.

When current is applied to the coiled wire, a magnetic field is formed that concentrates in the metal post. The magnetic force produced by the current pulls the armature toward the metal post until it touches Contact 2. A closed circuit now exists between Contact 2 and Contact 3. An open circuit exists between Contact 1 and Contact 3. The action of the armature, therefore, opens or closes the circuit.

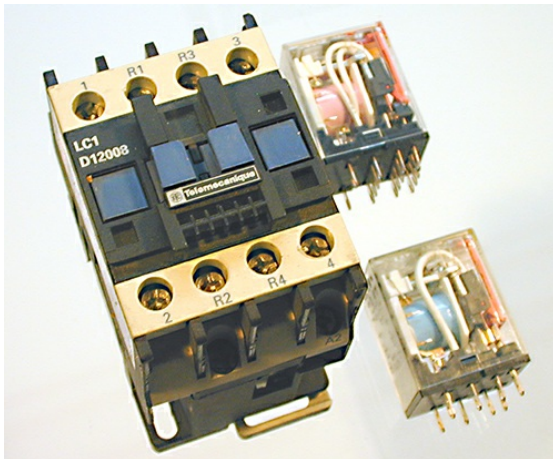


[An image of smaller circuit relays known as ice-cube relays]

Here are examples of the smaller circuit relays you'll encounter in industrial installations.

Relays come in a wide variety of sizes. The figure shows what are commonly called *ice-cube relays*. These small relays typically control relatively low-power loads such as small motors and heaters. They're typically mounted in sockets on a control board inside an electrical enclosure. Wires can then be connected to the terminals on the sockets to make the electrical connections to the relay's coil and the contacts.

To control larger, more powerful electrical loads, a circuit relies on larger relays, such as a *contactor*. The shown relay also includes coils and contacts; however, its coils and contacts are much larger to handle the greater current requirements of the bigger electrical loads.

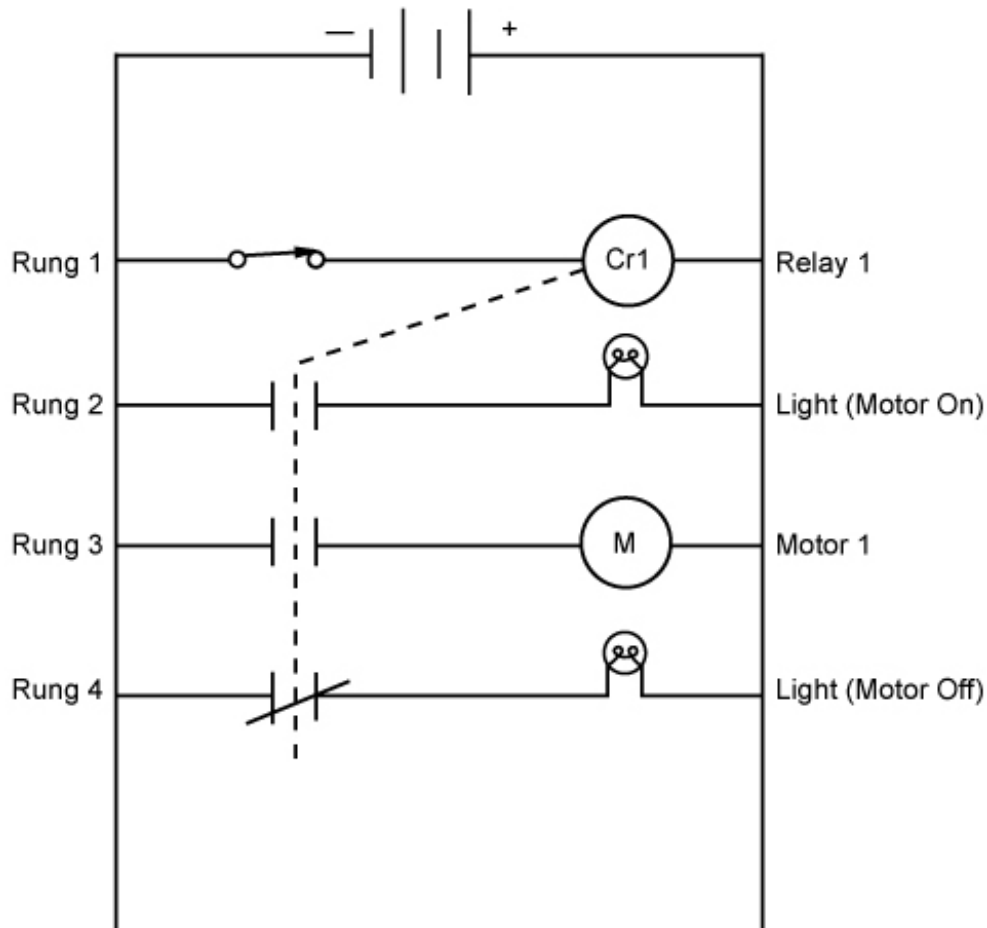


[An image of a larger relay known as a contactor used to control a larger electrical load]

This is a larger relay that can be used to control a much larger motor, heater, or other industrial electrical load.

There are two basic types of relay contacts: *normally open relay contacts* and *normally closed relay contacts*. A normally open relay contact closes the circuit when current is applied to it, and when current is removed it opens the circuit. When current is applied to a normally closed relay contact it breaks the circuit, and when current is removed from the relay, it closes the circuit.

Relays can perform many electrical or electronic circuit functions. For example, relays are used in remote control switches. Or, a relay can allow a low-current, low-voltage signal to control a much higher current load. Relays can also be used to control multiple output devices.



[An image of a relay ladder logic diagram]

In this relay circuit, the contacts of the relay will change when the coil of the relay is energized.

A typical relay circuit diagram is called a *relay ladder logic diagram*. This is because the diagram looks like a ladder with rails and rungs.

Note that the two vertical “rails” in the diagram are connected to the power source. The horizontal “rungs” of the diagram contain the switches, coils, and loads for the circuit. The rungs are actually simple series circuits that are connected between the power rails and

controlled by one relay contact on each rail.

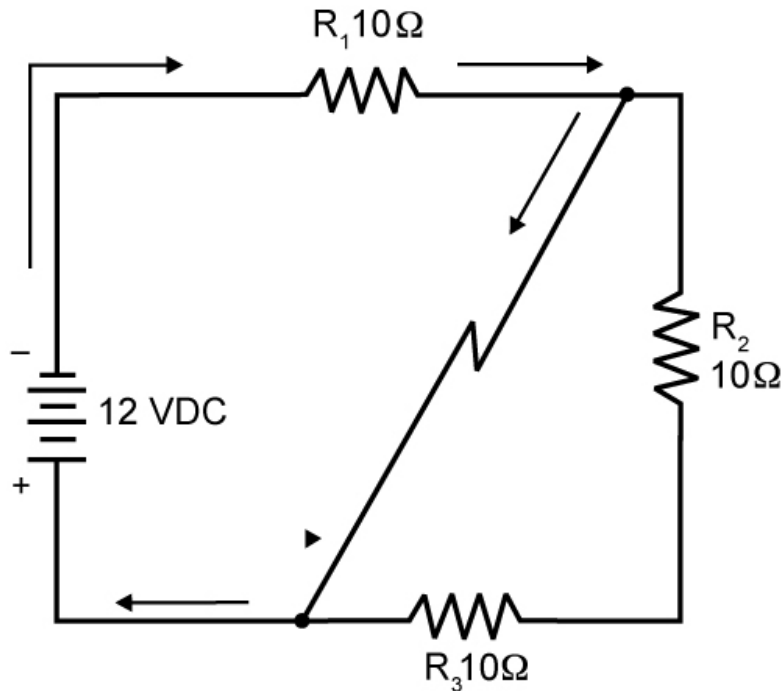
At Rung 1, a switch is used to control the relay Cr1. When the switch is closed, the relay's coil is energized. As a result of this action, the relay contacts in Rung 2, Rung 3, and Rung 4 transfer their state. That is, a normally open contact closes and a normally closed contact opens. When the switch is opened, the relay's coil is de-energized and the contacts return to their original state.

Rung 2 of the ladder logic diagram is used to power a light bulb. When the relay's coil is energized, the relay contact on this rung closes and turns on the light bulb.

Rung 3 is used to power a motor. When the relay's coil is energized, the relay contacts close and turn on the motor. The motor rotates until the relay is de-energized.

Rung 4 of this circuit contains a normally closed contact, so it operates in an opposite manner from the relays in the other rungs. In Rung 4, the light bulb glows when the relay contact is closed. When the relay's coil is energized, the normally closed contacts open and turn off the light bulb.

Short Circuits



[An image of an illustration of a short circuit within a series circuit]

In this illustration, current flows through the first resistor (R_1) and then short-circuits, bypassing the second and third resistors (R_2 and R_3). This greatly increases the current in the circuit.

In an electrical circuit, current will always follow the path of least resistance. Because of this, sometimes the current makes its own paths where there shouldn't be any. This is referred to as a *short circuit*. Short circuits often occur where two bare conductor wires touch or where a circuit is improperly wired. The electrical current “jumps” from one conductor to another at the point where there is the least resistance. Little or no current will flow into the areas beyond the

point where the short occurs.

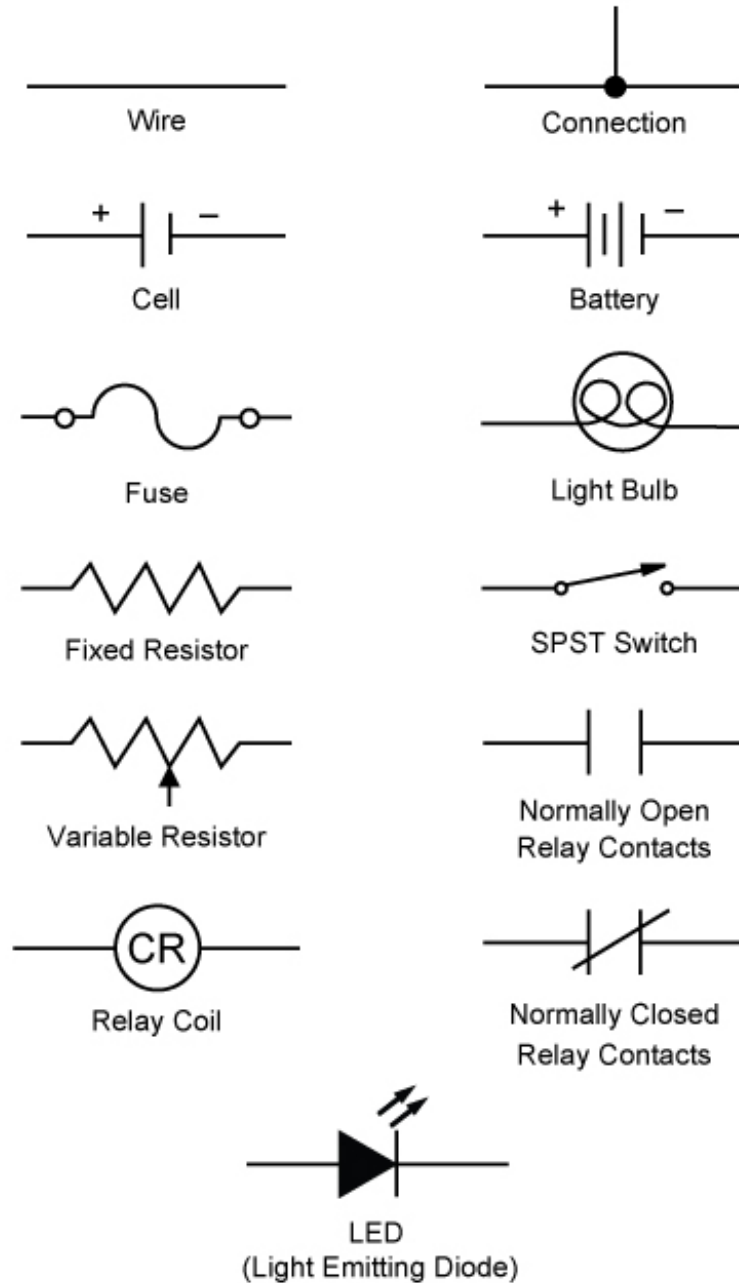
Thus, a short circuit creates a very low-resistance electrical path that carries almost all the current. The figure shows a short circuit within a series circuit. In this circuit, the current flows through the first resistor, then short circuits across, skipping the second and third resistors.

Key Points and Links

READING ASSIGNMENT

Key Points

- Schematics are simplified drawings of electrical circuits to show all the electrical components of a circuit including the power source, conductors, loads, switches, resistors, and others.



[An image of standard symbols used to indicate electrical components in schematic diagrams]

All electrical or electronic components are identified on schematic diagrams by standards symbols, as shown in the figure.

- Electrical components can be connected either in series or in parallel; both types connect several electrical components together.
- In a series circuit, the current has only one electrical path to follow.
- The current flows through each of the components, one after another, in a straight line, and remains the same through all of the series components.
- In a parallel circuit, the current has two or more electrical paths to follow.
- The electrons flow from the negative battery terminal, branch out into two or more electrical paths, flow through all the components in the circuit, and return to the positive battery terminal.
- When components are connected in a series circuit, if one is removed or burns out, the entire series will fail.
- When components are connected in a parallel circuit, if one is removed or burns out, the remaining components in the circuit will continue to function.

Exercise: DC Principles

Respond to the following based on your reading.

1. _____ are simplified drawings of electrical circuits.
2. The current in a/an _____ circuit has two or more electrical paths to follow.

3. A/An _____ relay closes the circuit when a current is applied to it and opens the circuit when the current is removed.
4. A/An _____ occurs when an electrical current bypasses resistors in a circuit by following the path of least resistance.
5. What type of diagram is used to show the functions in a relay circuit?

Exercise Answer Key:

Exercise: DC Principles

1. Schematics (or Schematic diagrams)
2. parallel
3. normally open
4. short circuit
5. Relay ladder logic diagram

Lesson 1 Review

Self-Check

1. What's the definition of a circuit?
 - a. A device or appliance that runs on electricity
 - b. A device used to turn the flow of electricity on and off
 - c. A complete electrical path
 - d. Wires that carry electricity

- 2.** What term did Ohm use to classify materials that carried no electricity, even when a high voltage was applied?
- a. Insulators
 - b. Blockers
 - c. Conductors
 - d. Resistors
- 3.** What metal is used as a standard against which the conductivities of other metals are rated?
- a. Copper
 - b. Aluminum
 - c. Lead
 - d. Silver
- 4.** Static electricity can be produced in how many different ways?
- a. Two
 - b. Four that are known with more ways suspected
 - c. One
 - d. Three
- 5.** Volts are a unit of measurement used to express the strength of what?
- a. EMF
 - b. Electron bond in an atom
 - c. Amperage
 - d. LED
- 6.** What's the unit of measurement for the amount of electric current flowing through a circuit?
- a. Amperage

- b. Volt
- c. Ohm
- d. EMF

7. The opposition that a circuit creates against the flow of electrical current, also known as electrical resistance, is measured in which unit?

- a. Ohms
- b. Coulombs
- c. Amps
- d. Volts

8. What's another way to express 10^3 ?

- a. m
- b. k
- c. Σ
- d. Ω

9. Wirewound resistors and carbon resistors are both examples of what?

- a. Fixed resistors
- b. Rheostats
- c. Relays
- d. Variable resistors

10. Terry knew that to replace the volume control on the radio he would need to find what sort of potentiometer?

- a. Nonlinear taper
- b. Audio taper
- c. Direct taper

- d. Linear taper
- 11.** What's the difference between potentiometers and rheostats?
- a. Potentiometers are bigger than rheostats.
 - b. One is fixed and the other is variable.
 - c. Rheostats can conduct higher currents.
 - d. Potentiometers can conduct higher currents.
- 12.** What part of a circuit do "normally open" and "normally closed" contacts belong to?
- a. Potentiometers
 - b. Rheostats
 - c. Relays
 - d. Resistors
- 13.** Which of the following statements is true of both series and parallel circuits?
- a. Several electrical components are connected together.
 - b. The current is split between parallel components.
 - c. The current has two or more electrical paths to follow.
 - d. The current has only one electrical path to follow.
- 14.** As discovered by Georg Ohm, the relationship between the volt, the ohm, and the ampere can be expressed as:
- a. $V = R \div I$
 - b. $R + I = V$
 - c. $I = R \div V$
 - d. $V = I \times R$
- 15.** Employees at Rodgerton Digital were responsible for handling and working closely with electronic components. As they did, they were

required to wear a grounding wrist strap to prevent _____ from damaging the equipment.

- a. power surges
- b. moisture
- c. dust
- d. static electricity

Self-Check Answer Key

1. A complete electrical path

Explanation: A circuit is defined as a complete electrical path. A typical circuit includes a power source, conductors, a load, and a switch.

Reference: Section 1.1

2. Insulators

Explanation: Insulators have atoms that are very tightly bonded. Examples of insulators are glass, mica, porcelain, paper, plastic, and rubber.

Reference: Section 1.1

3. Copper

Explanation: The conductivity ratings of other materials are expressed as percents relative to copper. Note that this doesn't mean that copper has no electrical resistance; it just means that copper is used as the standard that other materials are rated

against.

Reference: Section 1.1

4. Two

Explanation: Static electricity can be produced in two ways: by friction or induction.

Reference: Section 1.2

5. EMF

Explanation: The strength of EMF or electrical potential is measured in units called volts. The more volts that are present, the greater the electrical potential will be.

Reference: Section 1.2

6. Amperage

Explanation: The amount of electric current flowing through a circuit is called amperage. The amount of current is measured in units called amperes or amps.

Reference: Section 1.3

7. Ohms

Explanation: One ohm is equal to the resistance of a circuit in which one volt of EMF is applied to produce one ampere of current.

Reference: Section 1.3

8. k

Explanation: The symbol k stands for the prefix kilo whose value is 1,000.

Reference: Section 1.4

9. Fixed resistors

Explanation: Carbon resistors and wirewound resistors have fixed resistance values. That is, they provide an unchanging resistance to the current in a circuit.

Reference: Section 1.5

10. Audio taper

Explanation: Audio taper potentiometers are often used as volume controls on portable radios. This is because the rotation of the audio taper potentiometer provides a smoother adjustment.

Reference: Section 1.5

11. Rheostats can conduct higher currents.

Explanation: Rheostats may have a diameter of 1 to 8 in., so they're larger than ordinary potentiometers. Rheostats can conduct greater currents than potentiometers and are often used in motor, generator, or alternator circuits for speed or voltage control.

Reference: Section 1.5

12. Relays

Explanation: A normally open relay contact closes the circuit when current is applied to it, and when current is removed it opens the circuit. When current is applied to a normally closed relay contact it breaks the circuit, and when current is removed from the relay, it closes the circuit.

Reference: Section 1.5

13. Several electrical components are connected together.

Explanation: Electrical components can be connected together in two basic ways: in series or in parallel. In both types of circuits, several electrical components are connected together.

Reference: Section 1.6

14. $V = I \times R$

Explanation: V stands for voltage (in volts), the letter I stands for current (in amperes), and the letter R stands for resistance (in ohms). Ohm's law has many practical applications. Using the formula, you can determine the voltage, current, or resistance in any circuit.

Reference: Section 1.4

15. static electricity

Explanation: Workers must use extreme caution when handling circuit boards, computer components, and other electronic devices to prevent the potentially dangerous and damaging buildup of static electricity. When handling electronic

components, workers should stand on antistatic floor mats and wear grounding straps on their wrists to prevent static discharges.

Reference: Section 1.2

Flash Cards

1. Term: Circuit

Definition: A complete electrical path

2. Term: Conductors

Definition: Wires that allow the flow of electric current

3. Term: Resistors

Definition: Materials that pass some, but not all, current

4. Term: Insulators

Definition: Materials that don't carry electricity

5. Term: Static Electricity

Definition: Electricity that doesn't move through a circuit, though it still has much of the charge and power of electrical current

6. Term: Friction

Definition: Occurs when one material rubs against another

7. Term: Induction

Definition: The process by which an object receives a static charge by being placed near another charged object

8. Term: Grounding Device

Definition: When static charges build up in an object, the bonding strap or grounding device will conduct the charge from the object into the earth, neutralizing the charge.

9. Term: Volt

Definition: The work of one joule per coulomb

10. Term: Ampere

Definition: The movement of electrical charge at a rate of one coulomb per second

11. Term: Ohm

Definition: The resistance which allows a current of one ampere when an electromotive force of one volt is applied to a conductor

12. Term: Watt

Definition: The power exerted in a circuit with an electromotive force of one volt and a current of one ampere.

13. Term: V

Definition: Volt

14. Term: A

Definition: Ampere

15. Term: W

Definition: Watt

16. Term: Ω

Definition: Ohm

17. Term: Carbon Resistor

Definition: The most common type of resistor. Its body is made of resistive carbon surrounded by a composite sealing material, stiff wire leads protrude out of each end, and a series of colored bands identify the resistor's value as measured in ohms.

18. Term: Potentiometer

Definition: A control device used to adjust an electronic circuit

19. Term: Rheostat

Definition: A special type of potentiometer that conducts greater current and is often used in motor, generator, or alternator circuits for speed or voltage control

20. Term: Relay

Definition: A type of switch that works through electromagnetism

21. Term: Schematic Diagrams

Definition: Simplified drawings of electrical circuits that show all the electrical components of a circuit including the power source, conductors, loads, switches, resistors, and so on

22. Term: Series Circuit

Definition: Current has only one electrical path to follow

23. Term: Parallel Circuit

Definition: Current has two or more electrical paths to follow

24. Term: Short Circuit

Definition: Where two bare conductor wires touch or where a circuit is improperly wired, the electrical current “jumps” from one conductor to another at the point where there's the least resistance.