CHAPTER 10 Electricity

Chapter Outline

The giant electric pylon in this photo looks a little bit like a space alien marching across the land. The pylon supports heavy electric cables that carry electricity from the transfer station in the background to a distant city. The electricity that flows through wires in your home probably travels through cables on pylons like this one. Did you notice the other source of electricity in the photo? The brilliant bolt of lightning is a huge discharge of electricity from the clouds to the ground. Where do these two sources of electricity come from? In this chapter, you'll find out.

10.1 Electric Charge

Lesson Objectives

- Define electric charge and electric force.
- Describe electric fields.
- Identify ways that electric charge is transferred.

Lesson Vocabulary

- electric charge
- electric field
- electric force
- law of conservation of charge
- static discharge
- static electricity

Introduction

Has this ever happened to you? You walk across a carpet, reach out to touch a metal doorknob, and get an unpleasant electric shock (see **Figure** 10.1). The reason you get a shock is because of moving electric charges. Moving electric charges also create lightning bolts and the electric current that flows through cables and wires.

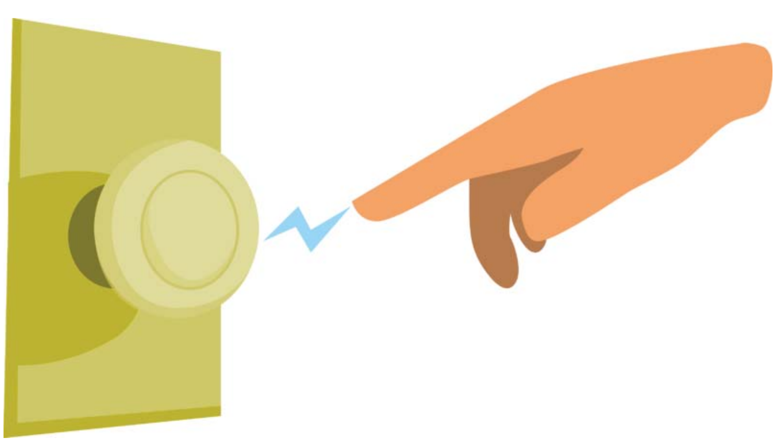


FIGURE 10.1
Moving electric charges explain why you get a shock when you touch a doorknob after walking across a carpet.

Electric Charge and Electric Force

Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching. All electric charge is based on the protons and electrons in atoms. A proton has a positive electric charge, and an electron has a negative electric charge (see **Figure** 10.2).

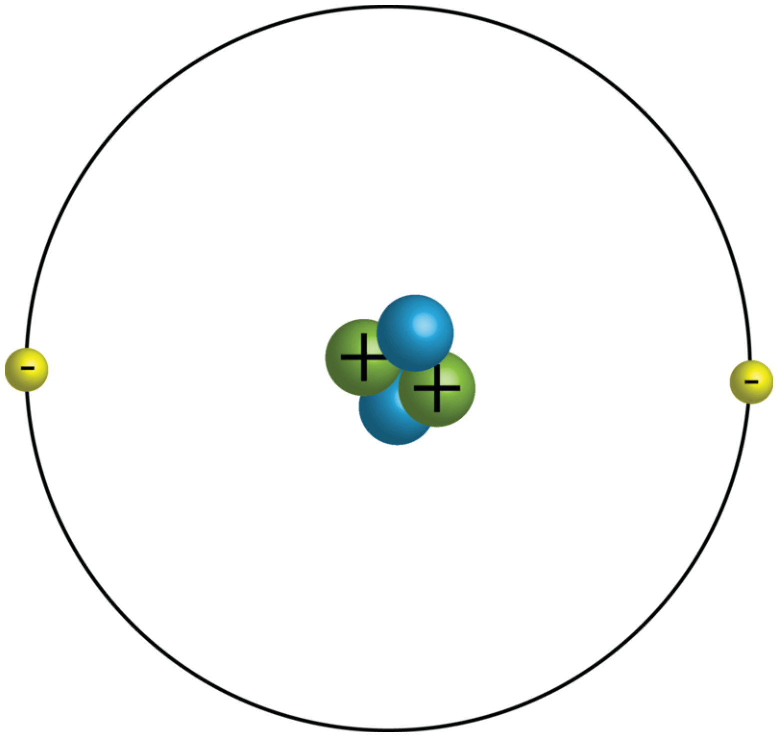


FIGURE 10.2

Positively charged protons (+) are located in the nucleus of an atom. Negatively charged electrons (-) move around the nucleus.

When it comes to electric charges, opposites attract. In other words, positive and negative particles are attracted to each other. Like charges, on the other hand, repel each other, so two positive or two negative charges push apart from each other. The force of attraction or repulsion between charged particles is called **electric force**. It is illustrated in **Figure** 10.3. The strength of electric force depends on the amount of electric charge and the distance between the charged particles. The larger the charge or the closer together the charges are, the greater is the electric force.

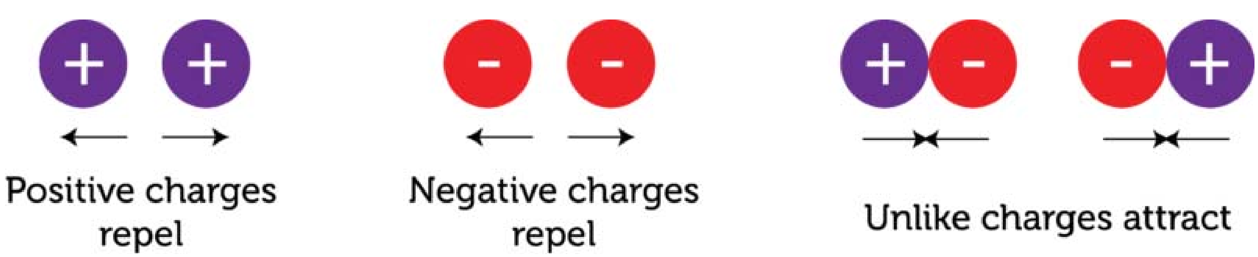


FIGURE 10.3

These diagrams illustrate the electric forces between charged particles.

Electric Fields

Electric force is exerted over a distance, so charged particles do not have to be in contact in order to exert force over each other. That's because each charged particle is surrounded by an electric field. An **electric field** is a space around a charged particle where the particle exerts electric force on other particles. Electric fields surrounding positively and negatively charged particles are illustrated in **Figure** 10.4 and at the URL below. When charged particles exert force on each other, their electric fields interact. This is also illustrated in **Figure** 10.4.

http://www.learnerstv.com/animation/animation.php?ani=86&cat=physics

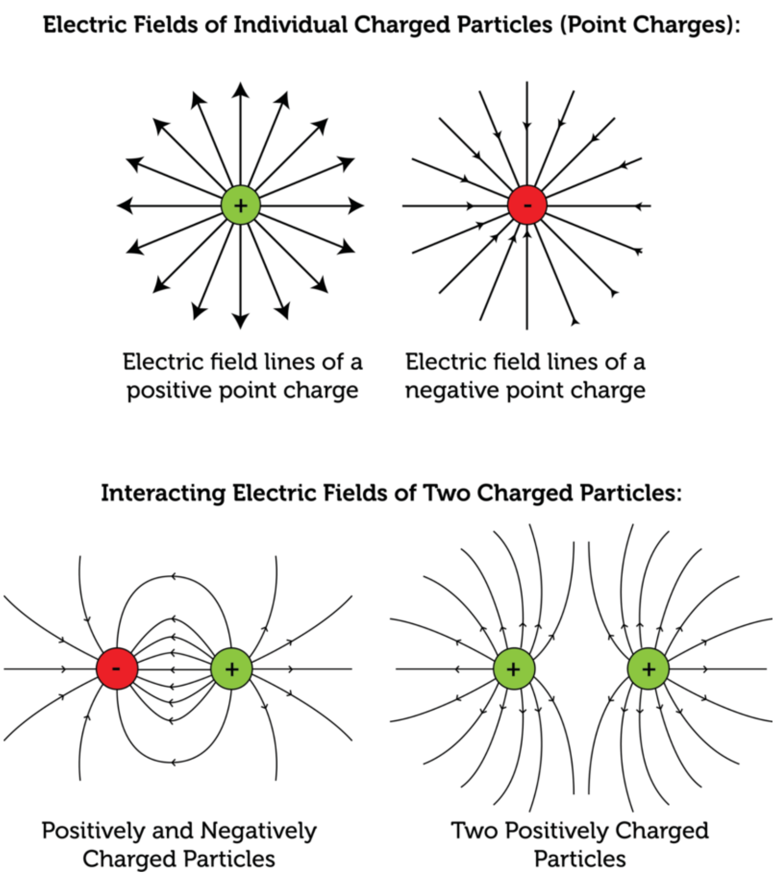


FIGURE 10.4

Field lines represent lines of force in the electric field around a charged particle. The lines bend when two particles interact. What would the lines of force look like around two negatively charged particles?

Transfer of Electric Charges

Atoms are neutral in electric charge because they have the same number of electrons as protons. However, atoms may transfer electrons and become charged ions, as illustrated in **Figure** 10.5. Positively charged ions, or cations, form when atoms give up electrons. Negatively charged ions, or anions, form when atoms gain electrons.

Like the formation of ions, the formation of charged matter in general depends on the transfer of electrons either between two materials or within a material. Three ways this can occur are friction, conduction, and polarization. In all cases, the total charge remains the same. Electrons move, but they aren't destroyed. This is the **law of conservation of charge**.

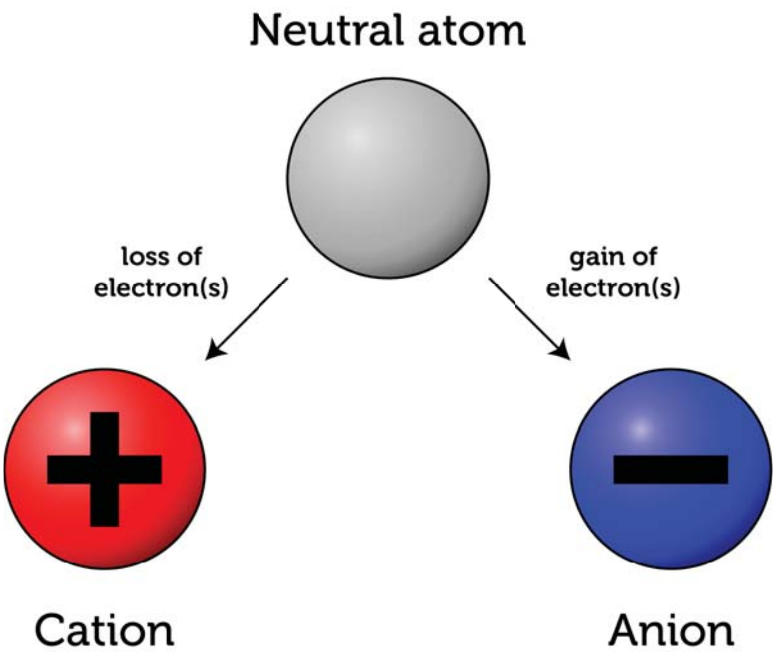


FIGURE 10.5
Atoms are electrically neutral, but if they lose or gain electrons they become charged particles called ions.

Friction

Did you ever rub an inflated balloon against your hair? You can see what happens in **Figure** 10.6. Friction between the rubber of the balloon and the baby's hair results in electrons from the hair "rubbing off" onto the balloon. That's because rubber attracts electrons more strongly than hair does. After the transfer of electrons, the balloon becomes negatively charged and the hair becomes positively charged. As a result, the individual hairs repel each other and the balloon and the hair attract each other. Electrons are transferred in this way whenever there is friction between materials that differ in their ability to give up or accept electrons.

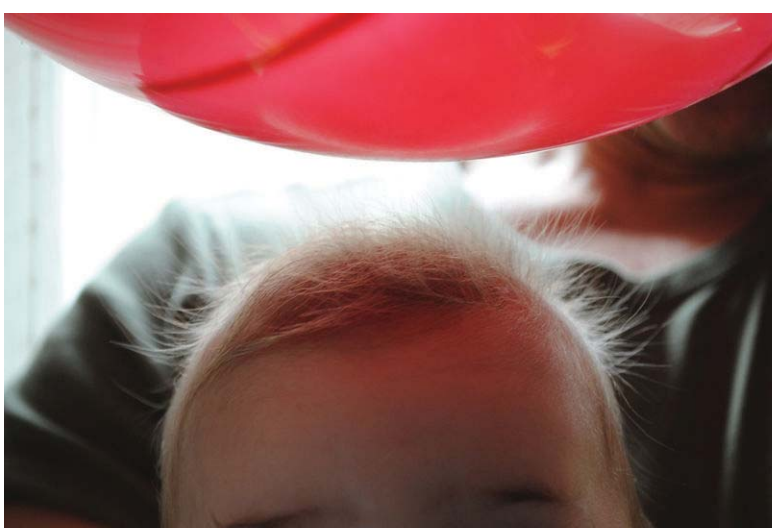


FIGURE 10.6
Electrons are transferred from hair to a balloon rubbed against the hair. Then the oppositely charged hair and balloon attract each other.

Conduction

Another way electrons may be transferred is through conduction. This occurs when there is direct contact between materials that differ in their ability to give up or accept electrons. For example, wool tends to give up electrons and rubber tends to accept them. Therefore, when you walk across a wool carpet in rubber-soled shoes, electrons transfer from the carpet to your shoes. You become negatively charged, while the carpet becomes positively charged.

Another example of conduction is pictured in **Figure** 10.7. The device this girl is touching is called a van de Graaff generator. The dome on top is negatively charged. When the girl places her hand on the dome, electrons are transferred to her, so she becomes negatively charged as well. Even the hairs on her head become negatively charged. As a result, individual hairs repel each other, causing them to stand on end. You can see a video demonstration of a van de Graff generator at this URL: http://www.youtube.com/watch?v=SREXQWAIDJk .

FIGURE 10.7

Electrons flow to the girl from the dome. She becomes negatively charged right down to the tips of her hair.

Polarization

Polarization is the movement of electrons within a neutral object due to the electric field of a nearby charged object. It occurs without direct contact between the two objects. You can see how it happens in **Figure** 10.8. When the negatively charged plastic rod in the figure is placed close to the neutral metal plate, electrons in the plate are repelled by the positive charges in the rod. The electrons move away from the rod, causing one side of the plate to become positively charged and the other side to become negatively charged.

Polarization may also occur after you walk across a wool carpet in rubber-soled shoes and become negatively charged. If you reach out to touch a metal doorknob, electrons in the neutral metal will be repelled and move away from your hand before you even touch the knob. In this way, one end of the doorknob becomes positively charged and the other end becomes negatively charged.

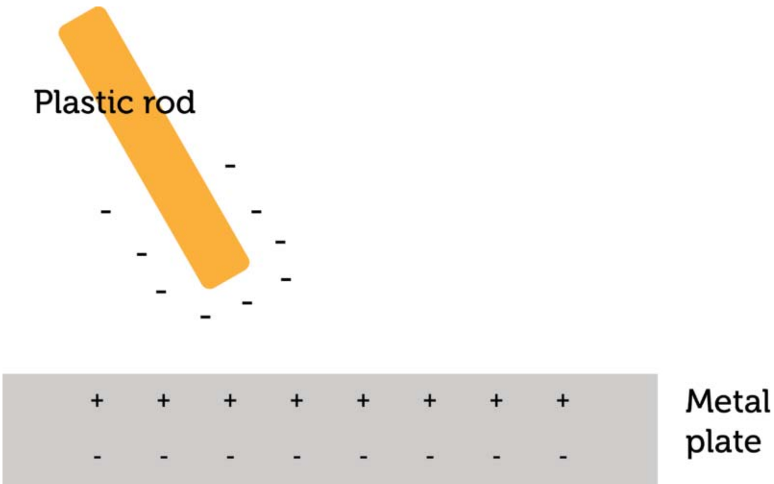


FIGURE 10.8
Polarization occurs between a charged and neutral object.

Static Electricity and Static Discharge

Polarization leads to the buildup of electric charges on objects. This buildup of charges is known as **static electricity**. Once an object becomes charged, it is likely to remain charged until another object touches it or at least comes very close to it. That's because electric charge cannot travel easily through air, especially if the air is dry.

Consider again the example of your hand and the metal doorknob. When your negatively charged hand gets very close to the positively charged doorknob, the air between your hand and the knob may become electrically charged. If that happens, it allows electrons to suddenly flow from your hand to the knob. This is the electric shock you feel when you reach for the knob. You may even see a spark as the electrons jump from your hand to the metal. This sudden flow of electrons is called **static discharge**. Another example of static discharge, on a much larger scale, is lightning. You can see how it occurs in **Figure** 10.9. At the URL below, you can watch a slow-motion lightning strike. Be sure to wait for the real-time lightning strike at the very end of the video.

http://www.youtube.com/watch?v=Y8oN0YFAXWQ

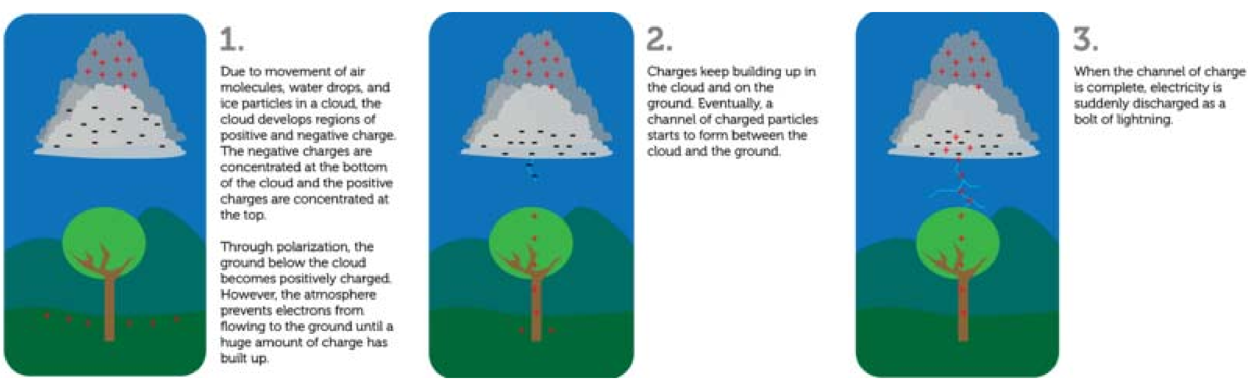


FIGURE 10.9
Lightning occurs when there is a sudden discharge of static electricity between a cloud and the ground.

Lesson Summary

- Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching. Positive and negative particles attract each other. Particles with the same charge repel each other. The force of attraction or repulsion between charged particles is called electric force.
- A charged particle can attract or repel other, nearby particles without touching them because it is surrounded by an electric field. This is a space around the particle where it exerts electric force on other particles.
- Objects become charged when they transfer electrons. This can happen through friction, conduction, or polarization. Although electrons are transferred, the total charge remains the same. Polarization may cause a buildup of charges on an object known as static electricity. Static discharge occurs when the built-up charges suddenly flow from the object. An example of static discharge is lightning.

Lesson Review Questions

Recall

1. Define electric charge.
2. Describe the forces between charged particles.
3. What is an electric field?
4. State the law of conservation of charge.
5. Outline how lightning occurs.

Apply Concepts

6. If you rub a piece of tissue paper on a plastic comb, the paper and comb stick together. Based on lesson concepts, explain why this happens.

Think Critically

7. Compare and contrast the ways that friction, conduction, and polarization transfer electric charge.

Points to Consider

You read in this lesson that lightning is a flow of electric charges. The electric current that flows through wires in your home is also a flow of electric charges. You'll read about electric current in the next lesson, "Electric Current."

- How might the electric current in a wire inside the walls of a house differ from a bolt of lightning?
- Lightning strikes may injure people or start fires. How do you think current can be used safely inside the walls of buildings?

10.2 Electric Current

Lesson Objectives

- Define electric current.
- Explain how voltage is related to electric current.
- Identify sources of voltage
- Relate electric current to materials.
- State Ohm's law.

Lesson Vocabulary

- alternating current (AC)
- direct current (DC)
- electric conductor
- electric current
- electric insulator
- Ohm's law
- resistance
- voltage

Introduction

When lightning discharges static electricity, it transfers a great deal of electric charge all at once. Such a sudden and large discharge of electricity isn't useful. You can't plug a toaster into a lightning bolt! To power appliances and other electric devices, you need a source of electricity that provides a relatively small amount of continuously flowing electric charges. The solution is an electric current.

Introduction to Electric Current

Electric current is a continuous flow of electric charges. Current is measured as the amount of charge that flows past a given point in a certain amount of time. The SI unit for electric current is the ampere (A), or amp. Electric current may flow in just one direction, or it may keep reversing direction.

- When current flows in just one direction, it is called **direct current (DC)**. The current that flows through a battery-powered flashlight is direct current.
- When current keeps reversing direction, it is called **alternating current (AC)**. The current that runs through the wires in your home is alternating current.

Graphs of both types of current are shown in **Figure** 10.10. You can watch an animation of both types at this URL: http://www.youtube.com/watch?v=JZjMuIHoBeg (0:10).

MEDIA
Click image to the left for more content.

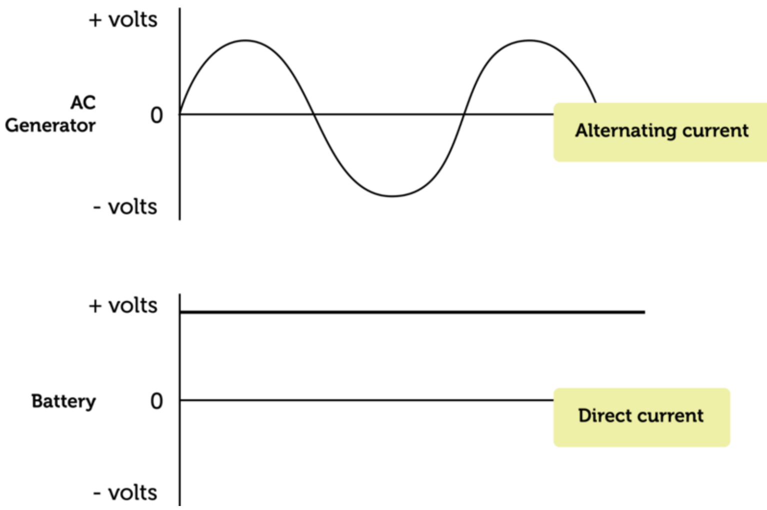


FIGURE 10.10
Direct current flows in one direction only, whereas alternating current keeps reversing direction.

Explaining Electric Current

Why do charges flow in an electric current? The answer has to do with electric potential energy. Potential energy is stored energy that an object has due to its position or shape. An electric charge has potential energy because of its position in an electric field. For example, when two negative charges are close together, they have potential energy because they repel each other and have the potential to push apart. If the charges move apart, their potential energy decreases. Electric charges always move spontaneously from a position where they have higher potential energy to a position where their potential energy is lower. This is similar to water falling over a dam from an area of higher to lower potential energy due to gravity.

In general, for an electric charge to move from one position to another, there must be a difference in electric potential energy between the two positions. The difference in electric potential energy is called potential difference, or **voltage**. Voltage is measured in an SI unit called the volt (V). For example, the terminals of the car battery in **Figure** 10.11 have a potential difference of 12 volts. This difference in voltage results in a spontaneous flow of charges, or electric current.

FIGURE 10.11
Most car batteries, like the one pictured here, are 12-volt batteries.

Sources of Voltage

Batteries like the one in **Figure** 10.11 are one of several possible sources of voltage needed to produce electric current. Sources of voltage include generators, chemical cells, and solar cells.

- Generators change the kinetic energy of a spinning turbine to electrical energy in a process called electromagnetic induction. You can read about generators and how they work in the chapter "Electromagnetism."
- Chemical and solar cells are devices that change chemical or light energy to electrical energy. You can read about both types of cells and how they work below.

Chemical Cells

Chemical cells are found in batteries. They produce voltage by means of chemical reactions. A chemical cell has two electrodes, which are strips made of different materials, such as zinc and carbon (see **Figure** 10.12). The electrodes are suspended in an electrolyte. An electrolyte is a substance containing free ions that can carry electric current. The electrolyte may be either a paste, in which case the cell is called a dry cell, or a liquid, in which case the cell is called a wet cell. Flashlight batteries contain dry cells. Car batteries contain wet cells. Animations at the URL below show how batteries work.

http://www.youtube.com/watch?v=EJeAuQ7pkpc

Both dry and wet cells work the same basic way. The electrodes react chemically with the electrolyte, causing one electrode to give up electrons and the other electrode to accept electrons. In the case of zinc and carbon electrodes, the zinc electrode attracts electrons and becomes negatively charged, while the carbon electrode gives up electrons and becomes positively charged. Electrons flow through the electrolyte from the negative to positive electrode. If wires are used to connect the two electrodes at their terminal ends, electric current will flow through the wires and can be used to power a light bulb or other electric device.

Solar Cells

Solar cells convert the energy in sunlight to electrical energy. They contain a material such as silicon that absorbs light energy and gives off electrons. The electrons flow and create electric current. **Figure** 10.13 and the animation at the URL below show how a solar cell uses light energy to produce electric current and power a light bulb. Many calculators and other devices are also powered by solar cells.

http://www.suntreksolar.com/solarElectricity/howCellsWork.asp

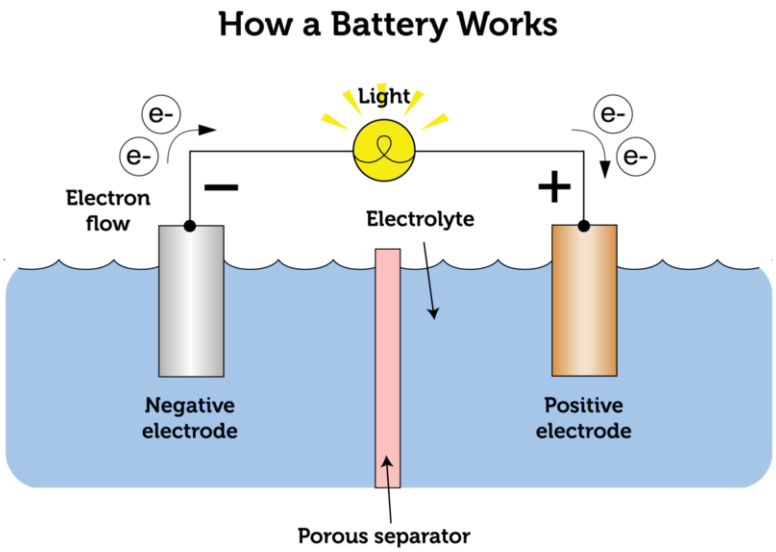


FIGURE 10.12
The simplest type of battery contains a single cell. The electrodes extend out of the battery for the attachment of wires that carry the current.

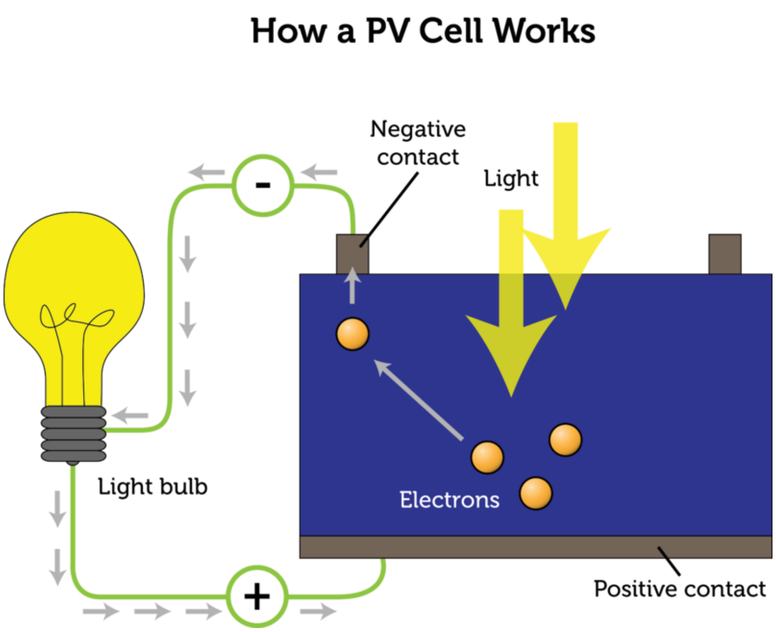


FIGURE 10.13
A solar cell is also called a photovoltaic (PV) cell because it uses light ("photo-") to produce voltage ("-voltaic"). The contacts in a PV cell are like the terminals in a chemical cell. One contact is negative and the other contact is positive, creating a difference in electric potential, or voltage, which produces electric current.

Electric Current and Materials

Electric current cannot travel through empty space. It needs a material through which to travel. However, when current travels through a material, the flowing electrons collide with particles of the material, and this creates resistance.

Resistance

Resistance is opposition to the flow of electric charges that occurs when electric current travels through matter. The SI unit of resistance is the ohm (named for the scientist Georg Ohm, whom you can read about below). Resistance is caused by electrons in a current bumping into electrons and ions in the matter through which the current is flowing. Resistance is similar to the friction that resists the movement of one surface as it slides over another. Resistance reduces the amount of current that can travel through the material because some of the electrical energy is converted to other forms of energy. For example, when electric current flows through the tungsten wire inside an incandescent light bulb, the tungsten resists the flow of electric charge, and some of the electrical energy is converted to light and thermal energy.

Electric Conductors and Insulators

Some materials resist the flow of electric current more or less than other materials do.

- Materials that have low resistance to electric current are called **electric conductors**. Many metals—including copper, aluminum, and steel—are good conductors of electricity. Water that has even a tiny amount of impurities in it is an electric conductor as well.
- Materials that have high resistance to electric current are called **electric insulators**. Wood, rubber, and plastic are examples of electric insulators. Dry air is also an electric insulator.

You probably know that electric wires are made of metal and coated with rubber or plastic (see **Figure** 10.14). Now you know why. Metals are good electric conductors, so they offer little resistance and allow most of the current to pass through. Rubber and plastic are good insulators, so they offer a lot of resistance and allow little current to pass through. When more than one material is available for electric current to flow through, the current always travels through the material with the least resistance. That's why all the current passes through a metal wire and none flows through its rubber or plastic coating.

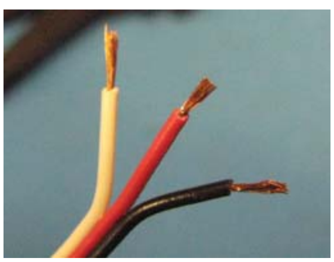


FIGURE 10.14

These electric cables are made of copper wires surrounded by a rubber coating.

Properties that Affect Resistance

For a given material, three properties of the material determine how resistant it is to electric current: length, width, and temperature. Consider an electric wire like one of the wires in **Figure** 10.14.

- A longer wire has more resistance. Current must travel farther, so there are more chances for it to collide with particles of wire.
- A wider wire has less resistance. A given amount of current has more room to flow through a wider wire.
- A cooler wire has less resistance than a warmer wire. Cooler particles have less kinetic energy, so they move more slowly. Current is less likely to collide with slowly moving particles. Materials called superconductors have virtually no resistance when they are cooled to extremely low temperatures. You can learn more about superconductors at this URL: http://www.dailymotion.com/video/x29bbd_superconductors_tech .

Ohm's Law

Voltage, or a difference in electric potential energy, is needed for electric current to flow. As you might have guessed, greater voltage results in more current. Resistance, on the other hand, opposes the flow of electric current, so greater resistance results in less current. These relationships between current, voltage, and resistance were first demonstrated by a German scientist named Georg Ohm in the early 1800s, so they are referred to as **Ohm's law**. Ohm's law can be represented by the following equation.

$$\text{Current (amps)} = \frac{\text{Voltage (volts)}}{\text{Resistance (ohms)}}$$

Understanding Ohm's Law

You may have a better understanding of Ohm's law if you compare current flowing through a wire from a battery to water flowing through a garden hose from a tap. Increasing voltage is like opening the tap wider. When the tap is opened wider, more water flows through the hose. This is like an increase in current. Stepping on the hose makes it harder for the water to pass through. This is like increasing resistance, which causes less current to flow through a material. Still not sure about the relationship among voltage, current, and resistance? Watch the video at this URL: http://www.youtube.com/watch?v=KvVTh3ak5dQ

MEDIA

Click image to the left for more content.

Using Ohm's Law to Calculate Current

You can use the equation for current (above) to calculate the amount of current flowing through a material when voltage and resistance are known. Consider an electric wire that is connected to a 12-volt battery. If the wire has a resistance of 3 ohms, how much current is flowing through the wire?

$$\text{Current} = \frac{12 \text{ volts}}{3 \text{ ohms}} = 4 \text{ amps}$$

You Try It!

Problem: A 120-volt voltage source is connected to a wire with 20 ohms of resistance. How much current flows through the wire?

Lesson Summary

- Electric current is a continuous flow of electric charge. It is measured in amperes (A). Direct current (DC) flows in just one direction. Alternating current (AC) keeps reversing direction.

- Electric current occurs whenever there is a difference in electric potential energy, or voltage. Voltage is measured in volts (V).
- Sources of voltage include electric generators and cells. Electric generators change kinetic energy to electrical energy. Chemical cells change chemical energy to electrical energy, and solar cells change solar energy to electrical energy.
- Electric current needs a material through which to travel, but particles of the material may resist the flow of current. Materials differ in how much they resist electric current. Materials with low resistance are called electric conductors, and materials with high resistance are called electric insulators.
- According to Ohm's law, current increases when voltage increases or resistance decreases. Current can be calculated as voltage divided by resistance.

Lesson Review Questions

Recall

1. What is electric current?
2. What is the difference between direct and alternating current?
3. Define voltage.
4. List three sources of voltage.
5. Identify three properties that affect the resistance of a given material.

Apply Concepts

6. A 12-volt battery is connected to a light bulb by wires. The wires and light bulb together have 6 ohms of resistance. How many amps of current are flowing through the wires?

Think Critically

7. Explain how voltage is related to electric current.
8. Compare and contrast electric conductors and electric insulators. Give an example of each.

Points to Consider

In this lesson, you learned about electric current. The next lesson, "Electric Circuits," focuses on the path that electric current travels. Think about a ceiling light with a wall switch. You probably have several in your home.

- What path does current travel to get from the switch on the wall to the light on the ceiling?
- How do you think the switch controls the flow of current to the light?

10.3 Electric Circuits

Lesson Objectives

- Identify the parts of an electric circuit.
- Define electric power, and state how to calculate electrical energy use.
- Identify electric safety features and how to use electricity safely.

Lesson Vocabulary

- electric circuit
- electric power
- parallel circuit
- series circuit

Introduction

Look at the battery and light bulb in **Figure** 10.15. The light bulb works and it's connected to the battery, but it won't light. The problem is the loose wire on the left. It must be connected to the positive terminal of the battery in order for the bulb to light up. The reason? Electric current can flow through a material such as a wire only if the material forms a closed loop. Charges must have an unbroken path to follow between the positively and negatively charged parts of the voltage source, in this case, the battery.

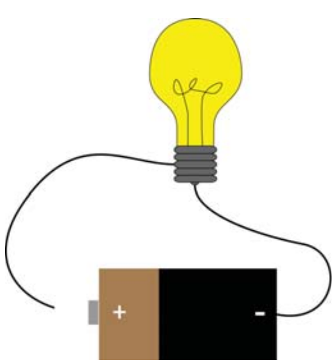


FIGURE 10.15
Electric current cannot flow through an open circuit.

Electric Circuit Basics

A closed loop through which current can flow is called an **electric circuit**. In homes in the U.S., most electric circuits have a voltage of 120 volts. The amount of current (amps) a circuit carries depends on the number and power of electrical devices connected to the circuit. But home circuits generally have a safe upper limit of about 20 or 30 amps.

Parts of an Electric Circuit

All electric circuits have at least two parts: a voltage source and a conductor.

- The voltage source of the circuit in **Figure** 10.16 is a battery. In a home circuit, the source of voltage is an electric power plant, which may supply electric current to many homes and businesses in a community or even to many communities.
- The conductor in most circuits consists of one or more wires. The conductor must form a closed loop from the source of voltage and back again. In **Figure** 10.16, the wires are connected to both terminals of the battery, so they form a closed loop.

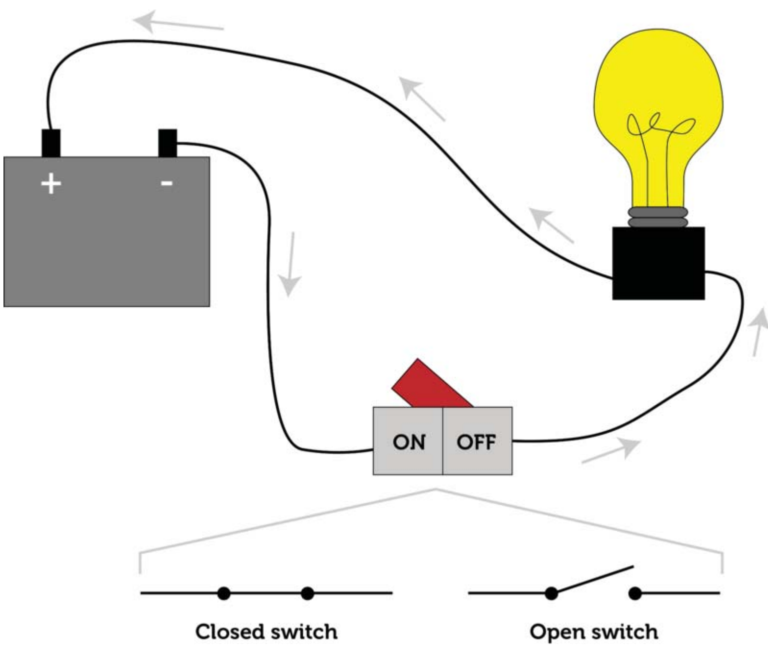


FIGURE 10.16

A circuit must be closed for electric devices such as light bulbs to work. The arrows in the diagram show the direction in which electrons flow through the circuit. The current is considered to flow in the opposite direction.

The circuit in **Figure** 10.16 also has two other parts: a light bulb and a switch. You can see a simple animation of a circuit like this at the URL below.

http://www.rkm.com.au/animations/animation-electrical-circuit.html

- Most circuits have devices such as light bulbs that convert electric energy to other forms of energy. In the case of a light bulb, electricity is converted to light and thermal energy.
- Many circuits have switches to control the flow of current through the circuit. When the switch is turned on, the circuit is closed and current can flow through it. When the switch is turned off, the circuit is open and current cannot flow through it.

Circuit Diagrams

When a contractor builds a new home, she uses a set of plans called blueprints that show her how to build the house. The blueprints include circuit diagrams that show how the wiring and other electrical components are to be installed in order to supply current to appliances, lights, and other electrical devices in the home. You can see an example of a very simple circuit diagram in **Figure** 10.17. Different parts of the circuit are represented by standard symbols, as defined in the figure. An ammeter measures the flow of current through the circuit, and a voltmeter measures the voltage. A resistor is any device that converts some of the electricity to other forms of energy. It could be a light bulb, doorbell, or similar device.

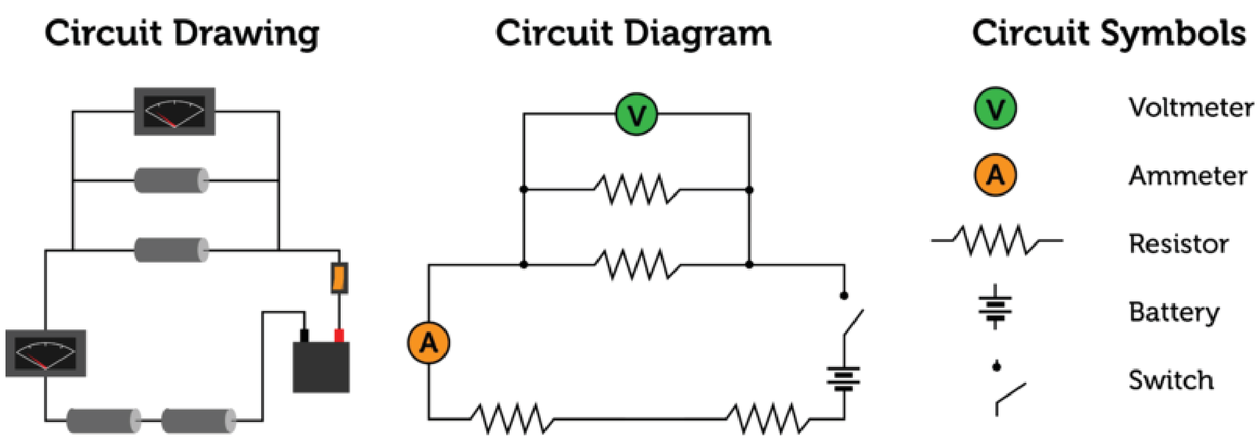


FIGURE 10.17
The circuit diagram on the right represents the circuit drawing on the left. To the right are some of the standard symbols used in circuit diagrams.

Series and Parallel Circuits

There are two basic types of electric circuits, called series and parallel circuits. They differ in the number of loops through which current can flow. You can see an example of each type of circuit in **Figure** 10.18.

- A **series circuit** has only one loop through which current can flow. If the circuit is interrupted at any point in the loop, no current can flow through the circuit and no devices in the circuit will work. In the series circuit in **Figure** 10.18, if one light bulb burns out the other light bulb will not work because it won't receive any current. Series circuits are commonly used in flashlights. You can see an animation of a series circuit at this URL: http://regentsprep.org/regents/physics/phys03/bsercir/default.htm .
- A **parallel circuit** has two (or more) loops through which current can flow. If the circuit is interrupted in one of the loops, current can still flow through the other loop(s). For example, if one light bulb burns out in the parallel circuit in **Figure** 10.18, the other light bulb will still work because current can by-pass the burned-out bulb. The wiring in a house consists of parallel circuits. You can see an animation of a parallel circuit at this URL: http://regentsprep.org/regents/physics/phys03/bsercir/default.htm .

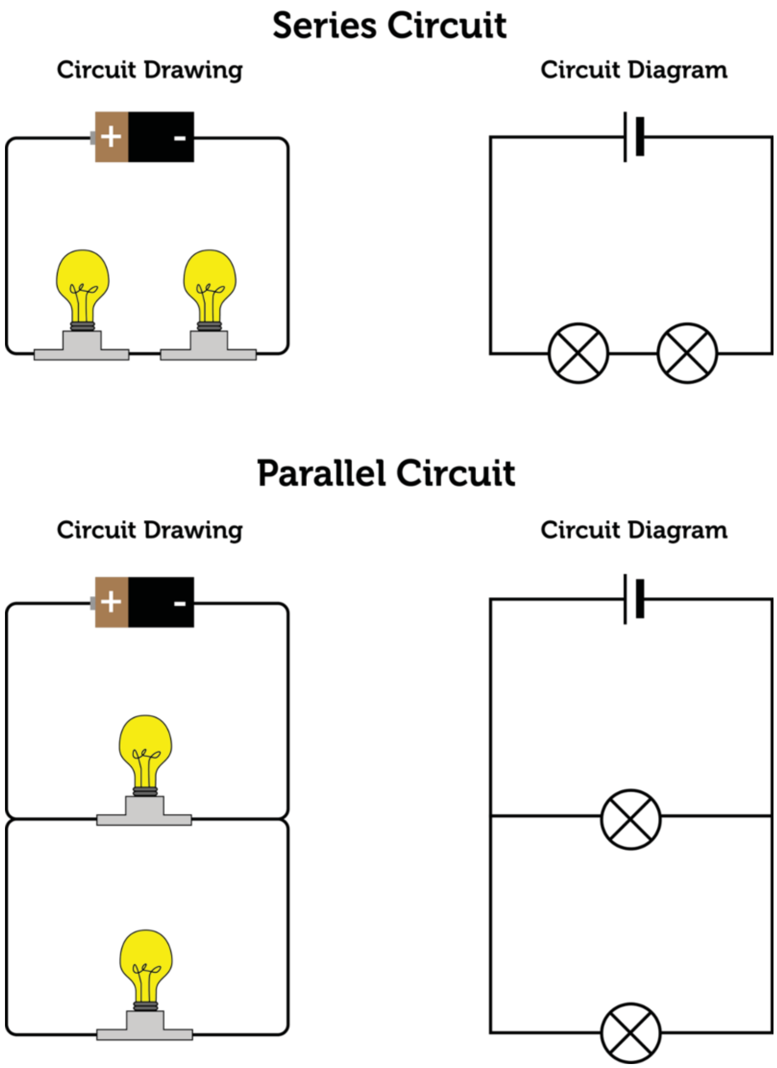


FIGURE 10.18

Series and parallel circuits differ in the number of loops they contain.

Electric Power and Electrical Energy Use

We use electricity for many purposes. Devices such as lights, stoves, and stereos all use electricity and convert it to energy in other forms. However, devices may vary in how quickly they change electricity to other forms of energy.

Electric Power

The rate at which a device changes electric current to another form of energy is called **electric power**. The SI unit of power—including electric power—is the watt. A watt equals 1 joule of energy per second. High wattages are often expressed in kilowatts, where 1 kilowatt equals 1000 watts. The power of an electric device, such as a microwave, can be calculated if you know the current and voltage of the circuit. This equation shows how power, current, and voltage are related:

$$\text{Power (watts)} = \text{Current (amps)} \times \text{Voltage (volts)}$$

Consider a microwave that is plugged into a home circuit. Assume the microwave is the only device connected to the circuit. If the voltage of the circuit is 120 volts and it carries 10 amps of current, then the power of the microwave is:

$$\text{Power} = 120 \text{ volts} \times 10 \text{ amps} = 1200 \text{ watts, or } 1.2 \text{ kilowatts}$$

You Try It!

Problem: A hair dryer is connected to a 120-volt circuit that carries 12 amps of current. What is the power of the hair dryer in kilowatts?

Electrical Energy Use

Did you ever wonder how much electrical energy it takes to use an appliance such as a microwave or hair dryer? Electrical energy use depends on the power of the appliance and how long it is used. It can be represented by the equation:

$$\text{Electrical Energy} = \text{Power} \times \text{Time}$$

Suppose you use a 1.2-kilowatt microwave for 5 minutes ($\frac{1}{12}$ hour). Then the energy used would be:

$$\text{Electrical Energy} = 1.2 \text{ kilowatts} \times \frac{1}{12} \text{ hour} = 0.1 \text{ kilowatt-hours}$$

Electrical energy use is typically expressed in kilowatt-hours, as in this example. How much energy is this? One kilowatt-hour equals 3.6 million joules of energy. Therefore, the 0.1 kilowatt-hours used by the microwave equals 0.36 million joules of energy.

You Try It!

Problem: A family watches television for an average of 2 hours per day. The television has 0.12 kilowatts of power. How much electrical energy does the family use watching television each day?

Electric Safety

Electricity is dangerous. Contact with electric current can cause severe burns and even death. Electricity can also cause serious fires. A common cause of electric hazards and fires is a short circuit.

How a Short Circuit Occurs

An electric cord contains two wires. One wire carries current from the outlet to the appliance or other electric device, and one wire carries current back to the outlet. Did you ever see an old appliance with a damaged cord, like the one in **Figure** 10.19? A damaged electric cord can cause a severe shock if it allows current to pass from the cord to a person who touches it. A damaged cord can also cause a short circuit. A short circuit occurs when electric current follows a shorter path than the intended loop of the circuit. For example, if the two wires in a damaged cord come into contact with each other, current flows from one wire to the other and bypasses the appliance. This may cause the wires to overheat and start a fire.

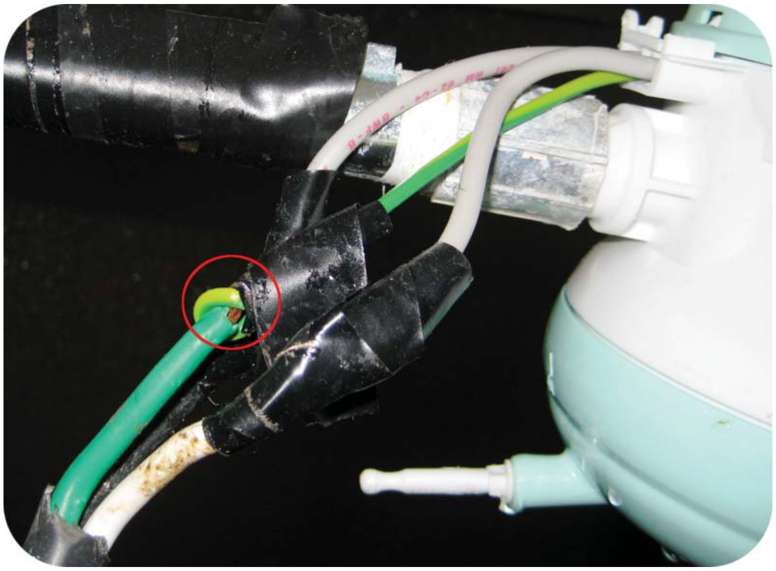


FIGURE 10.19
A damaged electric cord is a serious hazard. How can it cause an electric short?

Electric Safety Features

Because electricity can be so dangerous, safety features are built into electric circuits and devices. They include three-prong plugs, circuit breakers, and GFCI outlets. Each feature is described and illustrated in **Table** 10.1. You can learn more about electric safety features in the home by watching the video at this URL: http://www.dailymotion.com/video/x6fg5i_basics-of-your-home-s-electrical-sy_school .

TABLE 10.1: **Can you find one or more examples of these electric safety features in your home?**

Electric Safety Feature	Description
Three-Prong Plug 	A three-prong plug is generally used on metal appliances. The two flat prongs carry current to and from the appliance. The round prong is for safety. It connects with a wire inside the outlet that goes down into the ground. If any stray current leaks from the circuit or if there is a short circuit, the ground wire carries the current into the ground, which harmlessly absorbs it.
Circuit Breaker 	A circuit breaker is a switch that automatically opens a circuit if too much current flows through it. This could happen if too many electric devices are plugged into the circuit or if there is an electric short. Once the problem is resolved, the circuit breaker can be switched back on to close the circuit. Circuit breakers are generally found in a breaker box that controls all the circuits in a building.

TABLE 10.1: (continued)

Electric Safety Feature	Description
GFCI Outlet 	GFCI stands for ground-fault circuit interrupter. GFCI outlets are typically found in bathrooms and kitchens where the use of water poses a risk of shock (because water is a good electric conductor). A GFCI outlet contains a device that monitors the amounts of current leaving and returning to the outlet. If less current is returning than leaving, this means that current is escaping. When this occurs, a tiny circuit breaker in the outlet opens the circuit. The breaker can be reset by pushing a button on the outlet cover.

Using Electricity Safely

Even with electric safety features, electricity is still dangerous if it is not used safely. Follow the safety rules below to reduce the risk of injury or fire from electricity.

- Never mix electricity and water. Don't turn on or plug in electric lights or appliances when your hands are wet, you are standing in water, or you are in the shower or bathtub. The current could flow through the water—and you—because water is a very good electric conductor.
- Never overload circuits. Avoid plugging too many devices into one outlet or extension cord. The more devices that are plugged in, the more current the circuit carries. Too much current can overheat a circuit and start a fire.
- Never use devices with damaged cords or plugs. They can cause shocks, shorts, and fires.
- Never put anything except plugs into electric outlets. Plugging in other objects is likely to cause a serious shock that could be fatal.
- Never go near fallen electric lines. They could be carrying a lot of current. Report fallen lines to the electric company as soon as possible.

Lesson Summary

- An electric circuit is a closed loop through which electric current can flow. A circuit must include a source of voltage and conductors such as wires to carry the current from the source of voltage and back again. Types of circuits are series and parallel circuits.
- Electric power is the rate at which an electric device changes electric current to another form of energy. It is measured in watts or kilowatts and equals current (amps) times voltage (volts). The electrical energy used by a device is measured in kilowatt-hours and equals the power of the device (kilowatts) times the amount of time (hours) the device is used.
- Electricity is dangerous. Electric shorts can be hazardous and start fires. Electric safety features include three-prong plugs, circuit breakers, and GFCI outlets. Even with electric safety features, it's important to use electricity safely

Lesson Review Questions

Recall

1. Identify the parts of an electric circuit.
2. What is electric power?
3. What variables determine the amount of electrical energy an appliance uses?
4. Identify an electric safety feature and describe how it works.
5. List three tips to reduce the risk of injury or fire from electricity.

Apply Concepts

6. Draw a simple electric circuit that includes a battery, light bulb, and switch. Use arrows to show the flow of electrons through the circuit.
7. What is the power of an electric device that is connected to a 12-volt battery if the circuit is carrying 3 amps of current?

Think Critically

8. Compare and contrast series and parallel circuits.
9. Explain how a short circuit occurs.

Points to Consider

In this lesson, you read that electric devices convert electrical energy to other forms of energy. For example, a microwave oven converts electrical energy to electromagnetic energy in the form of microwaves. A blender converts electrical energy to sound energy and the kinetic energy of the whirring blades.

- Do you think all electric devices convert electrical energy to other forms of energy?
- Computers are familiar electric devices. Do you know how they use electric current?

10.4 Electronics

Lesson Objectives

- Describe electronic signals.
- Identify types of electronic components.
- Explain how computers use electronics.

Lesson Vocabulary

- electronics
- semiconductor

Introduction

Electric devices, such as lights and household appliances, change electric current to other forms of energy. For example, an electric stove changes electric current to thermal energy. Other common devices, such as mobile phones and computers, use electric current for another purpose: to encode information. The use of electric current for this purpose is called **electronics**.

Electronic Signals

Did you ever make a secret code? One way to make a code is to represent each letter of the alphabet by a different number. Then you can send a coded message by writing words as strings of digits. This is similar to how information is encoded using an electric current. The voltage of the current is changed rapidly and repeatedly to encode a message, called an electronic signal. There are two different types of electronic signals: analog signals and digital signals. Both are illustrated in **Figure** 10.20.

- A digital signal consists of pulses of voltage, created by repeatedly switching the current off and on. This type of signal encodes information as a string of 0s (current off) and 1s (current on). This is called a binary ("two-digit") code. DVDs, for example, encode sounds and pictures as digital signals.
- An analog signal consists of continuously changing voltage in a circuit. For example, microphones encode sounds as analog signals.

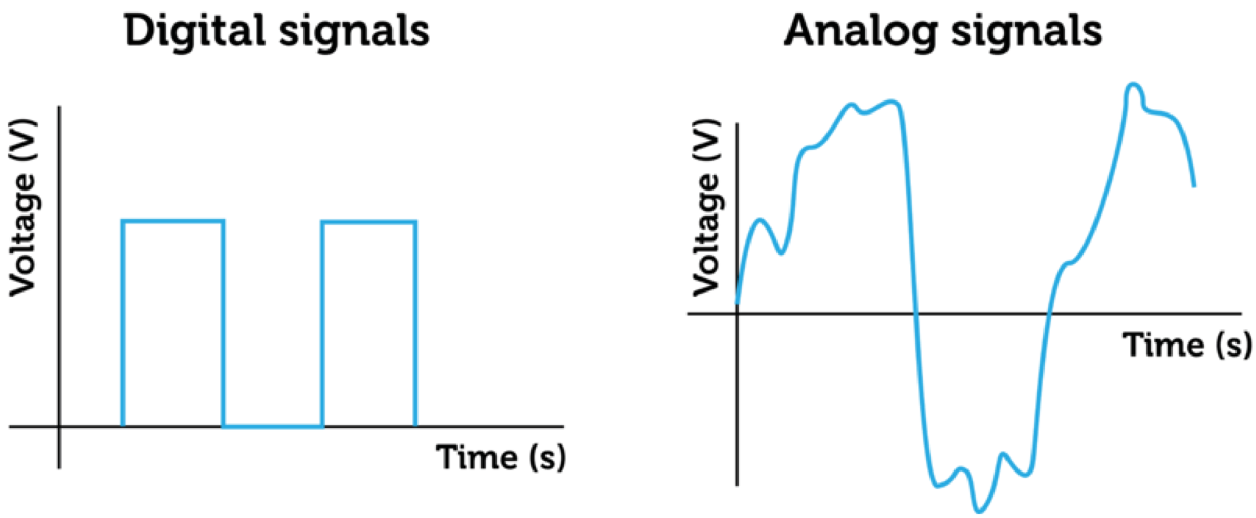


FIGURE 10.20
Digital and analog signals both change the voltage of an electric current, but they do so in different ways.

Electronic Components

Electronic components are the parts used in electronic devices such as computers. The components transmit and change electric current. They are made of materials called semiconductors.

Semiconductors

A **semiconductor** is a solid crystal—usually consisting mainly of silicon—that can conduct current better than an electric insulator but not as well as an electric conductor. Very small amounts of other elements, such as boron or phosphorus, are added to the silicon so it can conduct current. A semiconductor is illustrated in **Figure** 10.21.

There are two different types of semiconductors: n-type and p-type.

- An n-type semiconductor consists of silicon and an element such as phosphorus that gives the silicon crystal extra electrons. An n-type semiconductor is like the negative terminal in a chemical cell.
- A p-type semiconductor consists of silicon and an element such as boron that gives the silicon positively charged holes where electrons are missing. A p-type semiconductor is like the positive terminal in a chemical cell.

Types of Electronic Components

Electronic components contain many semiconductors. Types of components include diodes, transistors, and integrated circuits. Each type is described in **Table** 10.2.

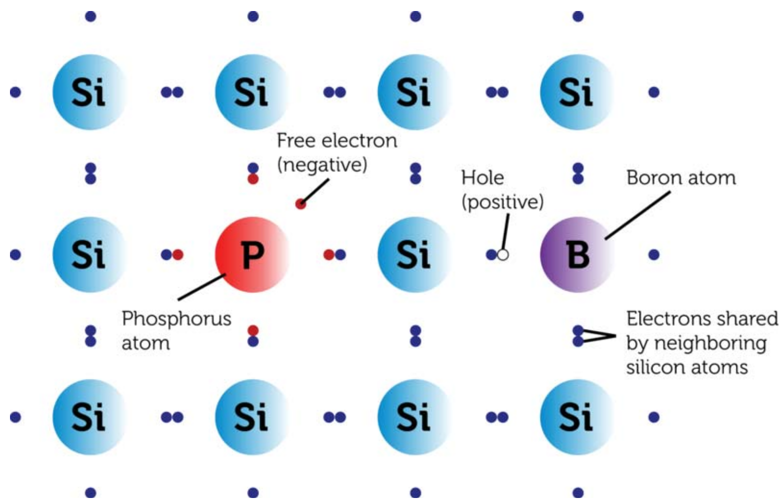
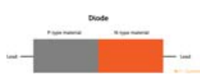
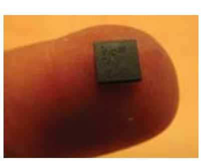


FIGURE 10.21
Each silicon atom has four valence electrons it shares with other silicon atoms in a crystal. A semiconductor is formed by replacing a few silicon atoms with other atoms that have more or less valence electrons than silicon.

TABLE 10.2: Semiconductors are the basis of each of these types of electronic components.

Electronic Component	Description
Diode 	A diode consists of a p-type and an n-type semiconductor placed side by side. When a diode is connected by leads to a source of voltage, electrons flow from the n-type to the p-type semiconductor. This is the only direction that electrons can flow in a diode. This makes a diode useful for changing alternating current to direct current.
Transistor 	A transistor consists of three semiconductors, either p-n-p or n-p-n. Current can't flow through a transistor unless a small amount of current is applied to the center semiconductor (through the base). Then a much larger current can flow through the transistor from end to end (from collector to emitter). This means that a transmitter can be used as a switch, with pulses of a small current turning a larger current on and off. A transistor can also be used to increase the amount of current flowing through a circuit. You can learn more about transistors and how they work at this URL: http://www.youtube.com/watch?v=ZaBLiciesOU (1:59).
Integrated Circuit (Microchip) 	An integrated circuit—also called a microchip—is a tiny, flat piece of silicon that consists of layers of electronic components such as transistors. An integrated circuit as small as a fingernail can contain millions of electronic components. Current flows extremely rapidly in an integrated circuit because it doesn't have far to travel. You can learn how microprocessors are made at this URL: http://www.youtube.com/watch?v=RHAso1yM-D4&feature=related (3:20).

Electronic Devices

Many of the devices you commonly use are electronic. Electronic devices include computers, mobile phones, TV

- ROM (read-only memory) is a microchip that provides permanent storage. It stores important information such as start-up instructions. This memory remains even after the computer is turned off.
- RAM (random-access memory) is a microchip that temporarily stores programs and data that are currently being used. Anything stored in RAM is lost when the computer is turned off.
- The motherboard is connected to the CPU, hard drive, ROM, and RAM. It allows all these parts of the computer to receive power and communicate with one another.

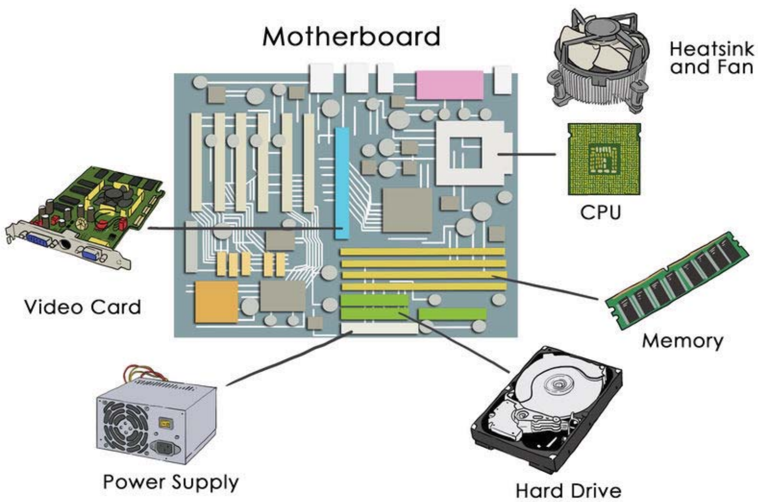


FIGURE 10.22

This illustration shows how the parts of a computer fit together.

Lesson Summary

- The use of electric current to encode information is called electronics. Electronic signals may be digital or analog signals. Both types of signals encode information by changing the voltage of an electric current, but they do so in different ways.
- Electronic components are the parts used in electronic devices. They are made of p-type and n-type semiconductors. Examples of electronic components include diodes, transistors, and integrated circuits (microchips).
- Electronic devices include computers, mobile phones, and TV remotes, to name just a few. All of them contain many electronic components that use electric current to encode, analyze, or transmit information.

Lesson Review Questions

Recall

1. What is an electronic signal?
2. Name two types of electronic signals. How do they differ?
3. Describe a semiconductor.
4. Identify one type of electronic component and state how it works.

Apply Concepts

5. Create an original binary code using the digits 0 and 1, and use it to encode a short message. Explain how your code is like the digital electronic code used in a computer.

Think Critically

6. Compare and contrast n-type and p-type semiconductors. Explain why both types of semiconductors must be used together in electronic components.

Points to Consider

In this chapter, you learned that electric charge is a physical property of some types of matter. In the chapter "Magnetism," you will read about another physical property of some types of matter —magnetism.

- If you've ever used a magnet, you already know something about magnetism. How would you define magnetism or explain it to someone who has no experience with magnets?
- Earth is considered to be a giant magnet. Do you know why?

For **Table** 10.1,

- Three-prong plug: Samuel M. Livingston. http://www.flickr.com/photos/39747297@N05/5229733647/ . CC BY 2.0.
- Circuit breaker: Flickr:davef3138. http://www.flickr.com/photos/davef3138/3573729611/ . CC BY 2.0.
- GFCI outlet: http://www.homespothq.com/. http://www.flickr.com/photos/86639298@N02/8560713440/ . CC BY 2.0.

For **Table** 10.2,

- Diode: Christopher Auyeung. CK-12 Foundation. CC BY-NC 3.0.
- Transistor: Christopher Auyeung. CK-12 Foundation. CC BY-NC 3.0.
- Integrated circuit (microchip): Flickr:fdecomite. http://www.flickr.com/photos/fdecomite/8157630452/ . CC BY 2.0.

10.5 References

1. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
2. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
3. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
4. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
5. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
6. Flickr:olga.palma. http://www.flickr.com/photos/marm0ta/6981900768/ . CC BY 2.0
7. Flickr:.dh. http://www.flickr.com/photos/25968780@N03/5113783724/ . CC BY 2.0
8. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
9. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
10. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
11. User:Shaddack/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Photo-CarBattery.jpg . Public Domain
12. Christopher Auyeung, based on diagram by User:Maxx/Wikimedia Commons. Original: http://commons.wikimedia.org/wiki/File:Galvanick%C3%BD_%C4%8Dl%C3%A1nek.svg . CC BY-NC 3.0 (original available in public domain)
13. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
14. Flickr:solarbotics. http://www.flickr.com/photos/solarbotics/5414548592/ . CC BY 2.0
15. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
16. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
17. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
18. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
19. Mat Honan. http://www.flickr.com/photos/honan/2225872023/ . CC BY 2.0
20. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
21. Christopher Auyeung. CK-12 Foundation . CC BY-NC 3.0
22. Laura Guerin. CK-12 Foundation . CC BY-NC 3.0