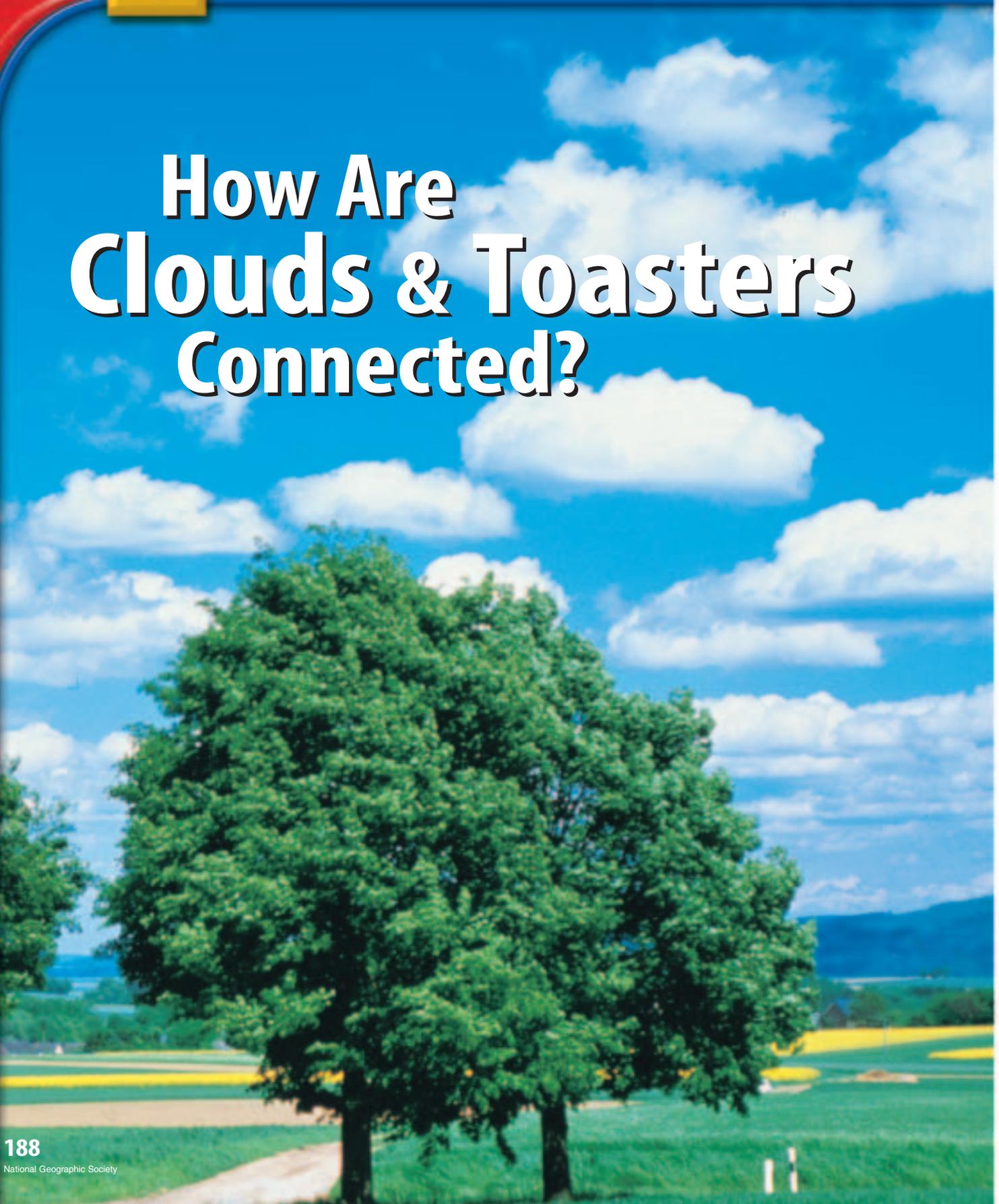


# How Are Clouds & Toasters Connected?



In the late 1800s, a mysterious form of radiation called X rays was discovered. One French physicist wondered whether uranium would give off X rays after being exposed to sunlight. He figured that if X rays were emitted, they would make a bright spot on a wrapped photographic plate. But the weather turned cloudy, so the physicist placed the uranium and the photographic plate together in a drawer. Later, on a hunch, he developed the plate and found that the uranium had made a bright spot anyway. The uranium was giving off some kind of radiation even without being exposed to sunlight! Scientists soon determined that the atoms of uranium are radioactive—that is, they give off particles and energy from their nuclei. In today's nuclear power plants, this energy is harnessed and converted into electricity. This electricity provides some of the power used in homes to operate everything from lamps to toasters.

**unit** **projects**

Visit [gpscience.com/unit\\_project](http://gpscience.com/unit_project) to find project ideas and resources.

Projects include:

- **History** Create a multimedia presentation of ten historical events and inventions that have affected today's society.
- **Technology** Design a safe, efficient, and economical cooking device. Draw blueprints, apply for a patent, and test your appliance. Choose a simple recipe to prepare. Submit your recipe, appliance, and food to the class.
- **Model** Construct a unit review game that demonstrates electricity or magnetism. Review information with an answer key should be provided in a well-designed, marketable package.



Using the *MagLev Trains* WebQuest, research, design, build, and test your own version of a maglev train, then present your model to the class.

# Electricity



## **BIG** Idea

The flow of electric charges in a circuit is a source of electrical energy.

### 7.1 Electric Charge

**MAIN** Idea Like electric charges attract each other and unlike charges repel.

### 7.2 Electric Current

**MAIN** Idea A voltage difference causes electrons to flow in a circuit.

### 7.3 Electrical Energy

**MAIN** Idea Electrical energy can be converted into other forms of energy in a circuit.

## Shine on Brightly

Electricity lights up this city so that people can continue to work or have fun when it gets dark. Electric lights and other electric devices operate by converting electrical energy into other forms of energy.

## Science Journal

For five electric devices, list the form of energy electrical energy is converted into by each device.

# Start-Up Activities



## Electric Circuits

No lights! No CD players! No computers, video games or TVs! Without electricity, many of the things that make your life enjoyable wouldn't exist. For these devices to operate, electric current must flow in the electric circuits that are part of the device. Under what conditions does electric current flow in an electric circuit?

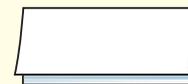


1. Obtain a battery, a flashlight bulb, and some wire.
2. Connect the materials so that the lightbulb lights.
3. Draw diagrams of all the ways that you were able to light the bulb.
4. Record a few of the ways that didn't work.
5. Can you light the bulb using only one wire and one battery?
6. **Think Critically** Write a paragraph describing the requirements to light the bulb. Write out a procedure for lighting the bulb and have a classmate follow your procedure.

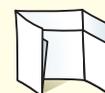
## FOLDABLES™ Study Organizer

**Electricity** Make the following Foldable to help you organize information about electricity.

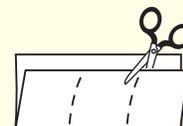
- STEP 1** **Fold** a vertical sheet of paper from top to bottom. Make the top edge about 2 cm shorter than the bottom edge.



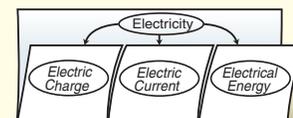
- STEP 2** **Turn** lengthwise and fold into thirds.



- STEP 3** **Unfold and cut** only the top layer along both folds to make three tabs.



- STEP 4** **Label** the Foldable as shown.



**Organize Information** As you read Chapter 7, organize the information you find about electric charge, electric current, and electrical energy under the appropriate tab.



Preview this chapter's content and activities at [gpscience.com](http://gpscience.com)

# Electric Charge

## Reading Guide

### What You'll Learn

- **Describe** how electric charges exert forces on each other.
- **Compare** the strengths of electric and gravitational forces.
- **Distinguish** between conductors and insulators
- **Explain** how objects become electrically charged.

### Why It's Important

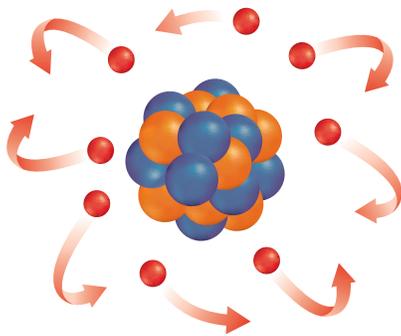
The electrical energy that all electrical devices use comes from the forces electric charges exert on each other.

### Review Vocabulary

**atom:** the smallest particle of an element

### New Vocabulary

- static electricity
- law of conservation of charge
- conductor
- insulator
- charging by contact
- charging by induction



**Figure 1** The center of an atom contains protons (orange) and neutrons (blue). Electrons (red) swarm around the atom's center.

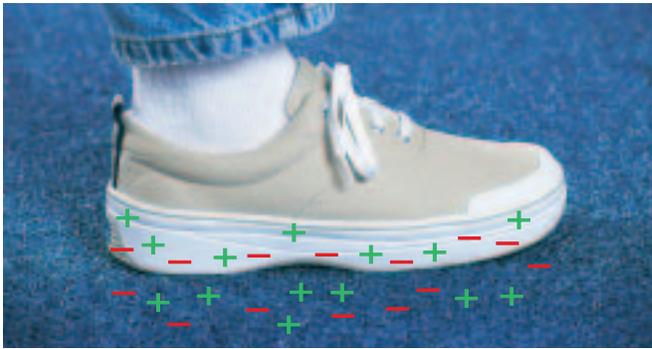
## Positive and Negative Charge

Why does walking across a carpeted floor and then touching something sometimes result in a shock? The answer has to do with electric charge. Atoms contain particles called protons, neutrons, and electrons, as shown in **Figure 1**. Protons and electrons have electric charge, and neutrons have no electric charge.

There are two types of electric charge. Protons have positive electric charge and electrons have negative electric charge. The amount of positive charge on a proton equals the amount of negative charge on an electron. An atom contains equal numbers of protons and electrons, so the positive and negative charges cancel out and an atom has no net electric charge. Objects with no net charge are said to be electrically neutral.

**Transferring Charge** Electrons are bound more tightly to some atoms and molecules. For example, compared to the electrons in carpet atoms, electrons are bound more tightly to the atoms in the soles of your shoes. **Figure 2** shows that when you walk on the carpet, electrons are transferred from the carpet to the soles of your shoes. The soles of your shoes have an excess of electrons and become negatively charged. The carpet has lost electrons and has an excess of positive charge. The carpet has become positively charged. The accumulation of excess electric charge on an object is called **static electricity**.

Before the shoe scuffs against the carpet, both the sole of the shoe and the carpet are electrically neutral.



As the shoes scuff against the carpet, electrons are transferred from the carpet to the soles of the shoes.



**Conservation of Charge** When an object becomes charged, charge is neither created nor destroyed. Usually it is electrons that have moved from one object to another. According to the **law of conservation of charge**, charge can be transferred from object to object, but it cannot be created or destroyed. Whenever an object becomes charged, electric charges have moved from one place to another.

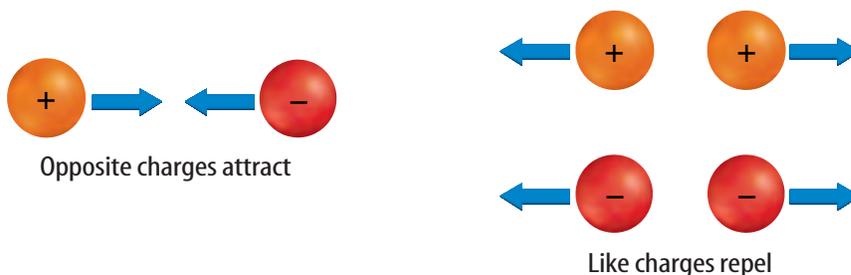
**Reading Check** *How does an object become charged?*

**Charges Exert Forces** Have you noticed how clothes sometimes cling together when removed from the dryer? These clothes cling together because of the forces electric charges exert on each other. **Figure 3** shows that unlike charges attract other, and like charges repel each other. The force between electric charges also depends on the distance between charges. The force decreases as the charges get farther apart.

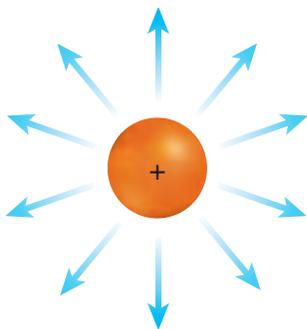
Just as for two electric charges, the force between any two objects that are electrically charged decreases as the objects get farther apart. This force also depends on the amount of charge on each object. As the amount of charge on either object increases, the electrical force also increases.

As clothes tumble in a dryer, the atoms in some clothes gain electrons and become negatively charged. Meanwhile the atoms in other clothes lose electrons and become positively charged. Clothes that are oppositely charged attract each other and stick together.

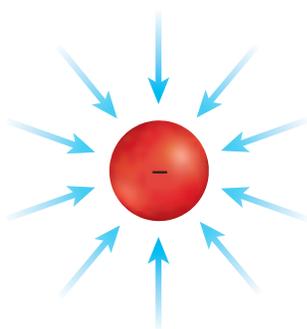
**Figure 2** Atoms in the shoe's sole hold their electrons more tightly than atoms in the carpet hold their electrons.



**Figure 3** Positive and negative charges exert forces on each other.



**Figure 4** Surrounding every electric charge is an electric field that exerts forces on other electric charges. The arrows point in the direction a positive charge would move.



**Electric Fields** You might have seen bits of paper fly up and stick to a charged balloon. The bits of paper do not need to touch the charged balloon for an electric force to act on them. If the balloon and the paper are not touching, what causes the paper to move?

An electric field surrounds every electric charge, as shown in **Figure 4**, and exerts the force that causes other electric charges to be attracted or repelled. Any charge that is placed in an electric field will be pushed or pulled by the field. Electric fields are represented by arrows that show how the electric field would make a positive charge move.

**Comparing Electric and Gravitational Forces** The force of gravity between you and Earth seems to be strong. Yet, compared with electric forces, the force of gravity is much weaker. For example, the attractive electric force between a proton and an electron in a hydrogen atom is about a thousand trillion trillion trillion times larger, or  $10^{39}$  times larger, than the attractive gravitational force between the two particles.

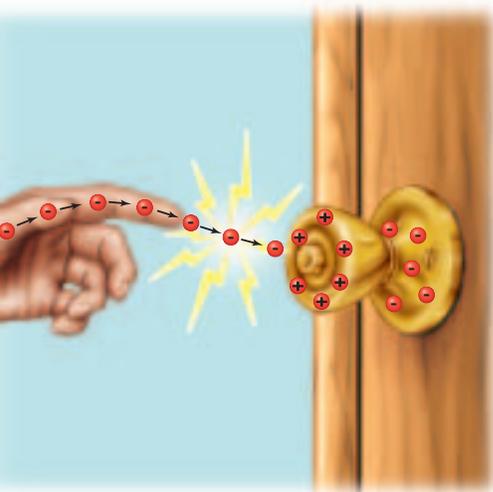
In fact, all atoms are held together by electric forces between protons and electrons that are tremendously larger than the gravitational forces between the same particles. The chemical bonds that form between atoms in molecules also are due to the electric forces between the atoms. These electric forces are much larger than the gravitational forces between the atoms.

**Reading Check** Compare the strength of electric and gravitational forces between protons and electrons.

However, the electric forces between the objects around you are much less than the gravitational forces between them. Most objects that you see are nearly electrically neutral and have almost no net electric charge. As a result, there is usually no noticeable electric force between these objects. But even if a small amount of charge is transferred from one object to another, the electric force between the objects can be noticeable.

For example, you probably have noticed your hair being attracted to a rubber comb after you comb your hair. Transferring about one trillionth of the electrons in a single hair to the comb results in an electric force strong enough to overcome the force of gravity on the strand of hair.

**Figure 5** As you walk across a carpeted floor, excess electrons can accumulate on your body. When you reach for a metal doorknob, electrons flow from your hand to the doorknob and you see a spark.



## Conductors and Insulators

If you reach for a metal doorknob after walking across a carpet, you might see a spark. The spark is caused by electrons moving from your hand to the doorknob, as shown in **Figure 5**. Recall that electrons were transferred from the carpet to your shoes. How did these electrons move from your shoes to your hand?

**Conductors** A material in which electrons are able to move easily is a **conductor**. Electrons on your shoes repel each other and some are pushed onto your skin. Because your skin is a better conductor than your shoes, the electrons spread over your skin, including your hand.

The best electrical conductors are metals. The atoms in metals have electrons that are able to move easily through the material. Electric wires usually are made of copper because copper metal is one of the best conductors.

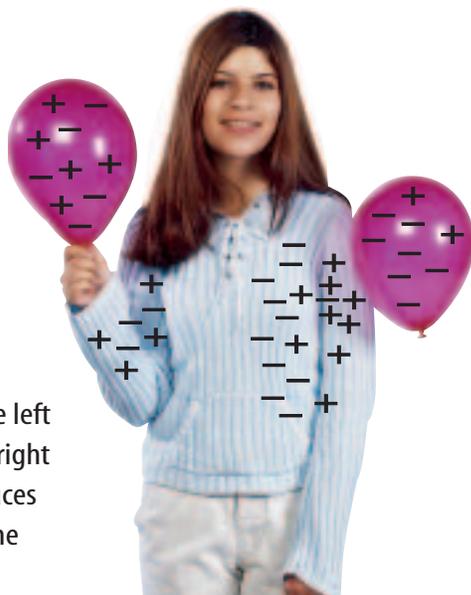
**Insulators** A material in which electrons are not able to move easily is an **insulator**. Electrons are held tightly to atoms in insulators. Most plastics are insulators. The plastic coating around electric wires, shown in **Figure 6**, prevents a dangerous electric shock when you touch the wire. Other good insulators are wood, rubber, and glass.

## Charging Objects

You might have noticed socks clinging to each other after they have been tumbling in a clothes dryer. Rubbing two materials together can result in a transfer of electrons. Then one material is left with a positive charge and the other with an equal amount of negative charge. The process of transferring charge by touching or rubbing is called **charging by contact**.



**Figure 6** The plastic coating around wires is an insulator. A damaged electrical cord is hazardous when the conducting wire is exposed.



**Figure 7** The balloon on the left is neutral. The balloon on the right is negatively charged. It produces a positively charged area on the sleeve by repelling electrons.

**Determine** the direction of the force acting on the balloon.

shown in **Figure 7**. As a result, the negatively charged balloon attracts the positively charged area of the sleeve. The rearrangement of electrons on a neutral object caused by a nearby charged object is called **charging by induction**. The sweater was charged by induction. The balloon will now cling to the sweater, being held there by an electrical force.

**Lightning** Have you ever seen lightning strike Earth? Lightning is a large static discharge. A static discharge is a transfer of charge between two objects because of a buildup of static electricity. A thundercloud is a mighty generator of static electricity. As air masses move and swirl in the cloud, areas of positive and negative charge build up. Eventually, enough charge builds up to cause a static discharge between the cloud and the ground. As the electric charges move through air, they collide with atoms and molecules. These collisions cause the atoms and molecules in air to emit light. You see this light as a spark, as shown in **Figure 8**.

**Thunder** Not only does lightning produce a brilliant flash of light, it also generates powerful sound waves. The electrical energy in a lightning bolt rips electrons off atoms in the atmosphere and produces great amounts of heat. The surrounding air temperature can rise to about 30,000°C—several times hotter than the Sun’s surface. The heat causes air in the bolt’s path to expand rapidly, producing sound waves that you hear as thunder.

The sudden discharge of so much energy can be dangerous. It is estimated that Earth is struck by lightning about 100 times every second. Lightning strikes can cause power outages, injury, loss of life, and fires.



**Topic: Lightning**

Visit [gpscience.com](http://gpscience.com) for Web links to information about lightning strikes.

**Activity** Make a table listing tips on how people can protect themselves from lightning.

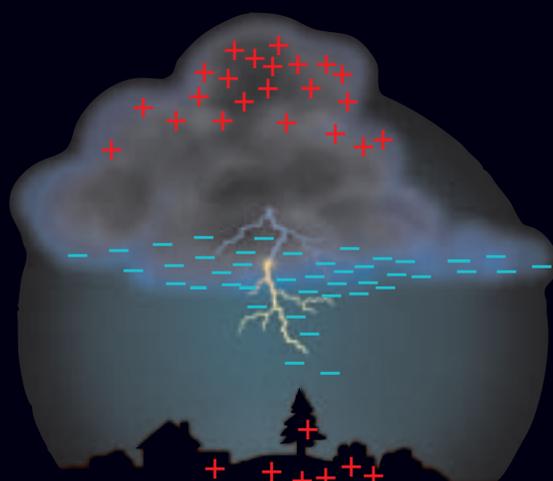
**Figure 8**

**S**torm clouds can form when humid, sun-warmed air rises to meet a colder air layer. As these air masses churn together, the stage is set for the explosive electrical display we call lightning. Lightning strikes when negative charges at the bottom of a storm cloud are attracted to positive charges on the ground.

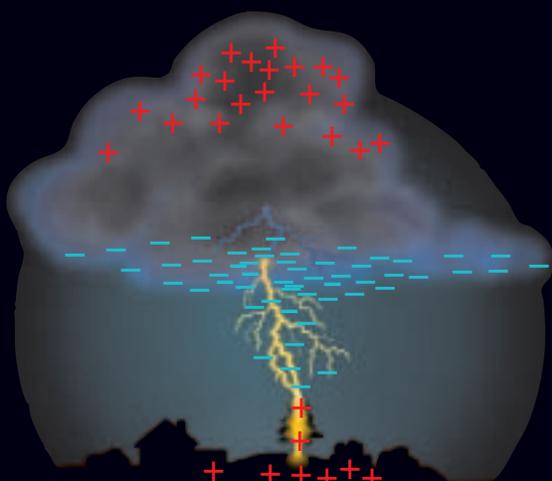
**A** Convection currents in the storm cloud cause charge separation. The top of the cloud becomes positively charged, the bottom negatively charged.



**B** Negative charges on the bottom of the cloud induce a positive charge on the ground below the cloud by repelling negative charges in the ground.



**C** When the bottom of the cloud has accumulated enough negative charges, the attraction of the positive charges below causes electrons in the bottom of the cloud to move toward the ground.



**D** When the electrons get close to the ground, they attract positive charges that surge upward, completing the connection between cloud and ground. This is the spark you see as a lightning flash.



**INTRA-CLOUD LIGHTNING** never strikes Earth and can occur ten times more often in a storm than cloud-to-ground lightning.

**Figure 9** A lightning rod directs the charge from a lightning bolt safely to the ground.

## Mini LAB

### Investigate Charged Objects

#### Procedure

1. Fold over about 1 cm on the end of a roll of transparent tape to make a handle. Tear off a strip of tape about 10 cm long.
2. Stick the strip to a clean, dry, smooth surface, such as a countertop. Make another identical strip and stick it directly on top of the first.
3. Pull both pieces off the counter together and pull them apart. Then bring the nonsticky sides of both tapes together. What happens?
4. Now stick the two strips of tape side by side on the smooth surface. Pull them off and bring the nonsticky sides near each other again.

#### Analysis

1. What happened when you first brought the pieces close together? Were they charged alike or opposite? What might have caused this?
2. What did you observe when you brought the pieces together the second time? How were they charged? What did you do differently that might have changed the behavior?



**Grounding** The sensitive electronics in a computer can be harmed by large static discharges. A discharge can occur any time that charge builds up in one area. Providing a path for charge to reach Earth prevents any charge from building up. Earth is a large, neutral object that is also a conductor of charge. Any object connected to Earth by a good conductor will transfer any excess electric charge to Earth. Connecting an object to Earth with a

conductor is called grounding. For example, buildings often have a metal lightning rod that provides a conducting path from the highest point on the building to the ground to prevent damage by lightning, as shown in **Figure 9**.

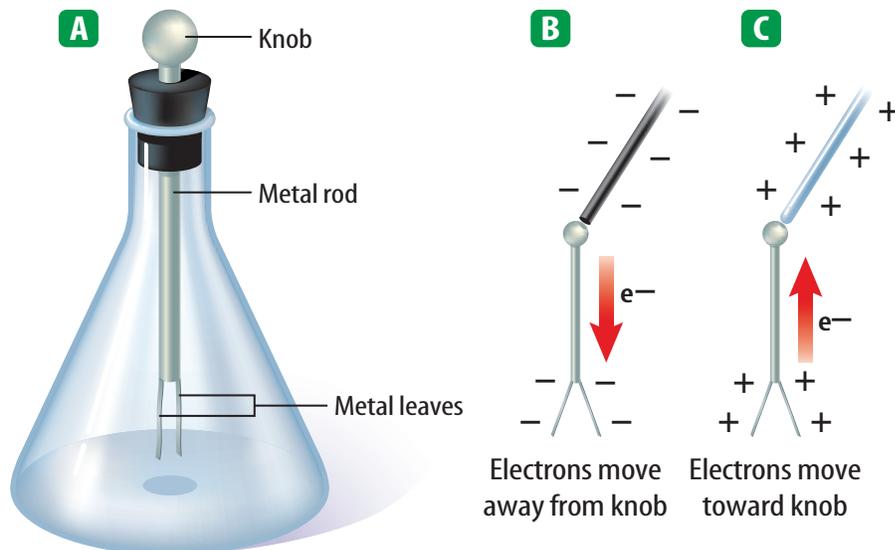
Plumbing fixtures, such as metal faucets, sinks, and pipes, often provide a convenient ground connection. Look around. Do you see anything that might act as a path to the ground?

## Detecting Electric Charge

The presence of electric charges can be detected by an electroscope. One kind of electroscope is made of two thin, metal leaves attached to a metal rod with a knob at the top. The leaves are allowed to hang freely from the metal rod. When the device is not charged, the leaves hang straight down, as shown in **Figure 10A**.

Suppose a negatively charged balloon touches the knob. Because the metal is a good conductor, electrons travel down the rod into the leaves. Both leaves become negatively charged as they gain electrons, as shown in **Figure 10B**. Because the leaves have similar charges, they repel each other.

If a glass rod is rubbed with silk, electrons move away from the atoms in the glass rod and build up on the silk. The glass rod becomes positively charged.



**Figure 10** Notice the position of the leaves on the electrostatic demonstrator when they are **A** uncharged, **B** negatively charged, and **C** positively charged.

**Infer** How can you tell whether an electrostatic demonstrator is positively or negatively charged?

When the positively charged glass rod is brought into contact with the metal knob of an uncharged electrostatic demonstrator, electrons flow out of the metal leaves and onto the rod. The leaves repel each other because each leaf becomes positively charged as it loses electrons, as shown in **Figure 10C**.

## section 1 review

### Summary

#### Positive and Negative Charge

- There are two types of electric charge—positive charge and negative charge.
- Electric charges can be transferred between objects, but cannot be created or destroyed.
- Like charges repel and unlike charges attract.
- An electric charge is surrounded by an electric field that exerts forces on other charges.

#### Electrical Conductors and Insulators

- A conductor contains electrons that can move easily. The best conductors are metals.
- The electrons in an electrical insulator do not move easily. Rubber, glass, and most plastics are examples of insulators.

#### Charging Objects

- Electric charge can be transferred between objects by bringing them into contact.
- Charging by induction occurs when the electric field around a charged object rearranges electrons in a nearby neutral object.

### Checking Concepts

1. **Define** static electricity.
2. **Describe** how lightning is produced.
3. **Explain** why if charge cannot be created or destroyed, electrically neutral objects can become electrically charged.
4. **Predict** what would happen if you touched the knob of a positively charged electrostatic demonstrator with another positively charged object.
5. **Think Critically** Humid air is a better electrical conductor than dry air. Explain why you're more likely to receive a shock after walking across a carpet when the air is dry than when the air is humid.

### Applying Math

6. **Determine Lightning Strikes** Suppose Earth is struck by 100 lightning strikes each second. How many times is Earth struck by lightning in one day?
7. **Calculate Electric Force** A balloon with a mass of 0.020 kg is charged by rubbing and then is stuck to the ceiling. If the acceleration of gravity is  $9.8 \text{ m/s}^2$ , what is the electrical force on the balloon?

# Electric Current

## Reading Guide

### What You'll Learn

- **Describe** how voltage difference causes current to flow.
- **Explain** how batteries produce a voltage difference in a circuit.
- **List** the factors that affect an object's electrical resistance.
- **Define** Ohm's law.

### Why It's Important

You control electric current every time you change the volume on a TV, stereo, or CD player.

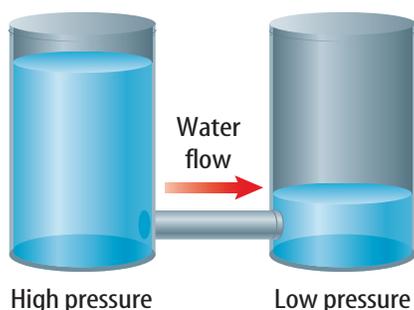
### Review Vocabulary

**pressure:** amount of force exerted per unit area

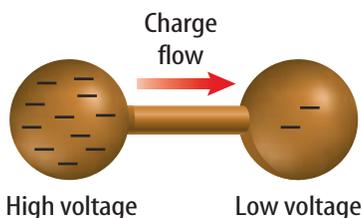
### New Vocabulary

- electric current
- voltage difference
- circuit
- resistance
- Ohm's law

**Figure 11** Electric forces in a material cause electric current to flow, just as forces in the water cause water to flow.



The force that causes water to flow is related to a pressure difference.



The force that causes a current to flow is related to a voltage difference.

## Current and Voltage Difference

When a spark jumps between your hand and a metal door-knob, electric charges move quickly from one place to another. The net movement of electric charges in a single direction is an **electric current**. In a metal wire, or any material, electrons are in constant motion in all directions. As a result, there is no net movement of electrons in one direction. However, when an electric current flows in the wire, electrons continue their random movement, but they also drift in the direction that the current flows.

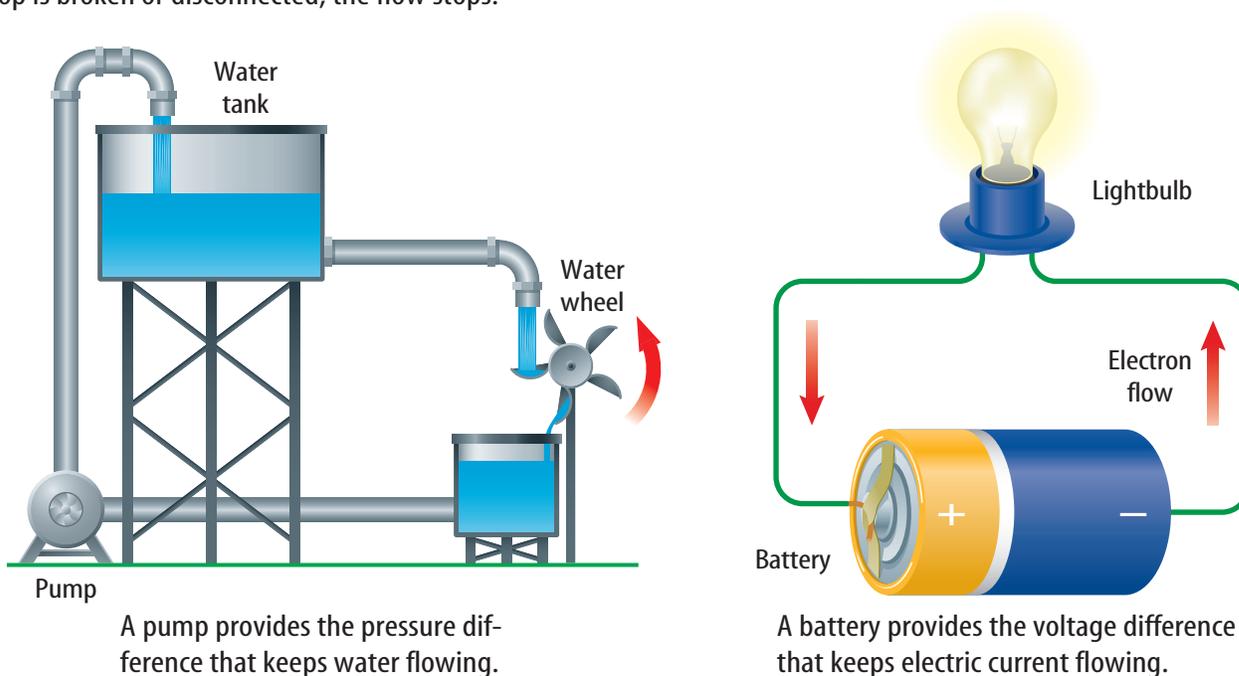
Electric current is measured in amperes. One ampere is equal to 6,250 million billion electrons flowing past a point every second.

### Reading Check *What is electric current?*

**Voltage Difference** The movement of an electron in an electric current is similar to a ball bouncing down a flight of stairs. Even though the ball changes direction when it strikes a stair, the net motion of the ball is downward. The downward motion of the ball is caused by the force of gravity. When a current flows, the net movement of electric charges is caused by an electric force acting on the charges.

In some ways, the electric force that causes charges to flow is similar to the force acting on the water in a pipe. Water flows from higher pressure to lower pressure, as shown in **Figure 11**. In a similar way, electric charge flows from higher voltage to lower voltage. A **voltage difference** is related to the force that causes electric charges to flow. Voltage difference is measured in volts.

**Figure 12** Water or electric current will flow continually only through a closed loop. If any part of the loop is broken or disconnected, the flow stops.



**Electric Circuits** A way to have flowing water perform work is shown in **Figure 12**. Water flows out of the tank and falls on a paddle wheel, causing it to rotate. A pump then provides a pressure difference that lifts the water back up into the tank. The constant flow of water would stop if the pump stopped working. The flow of water also would stop if one of the pipes broke. Then water no longer could flow in a closed loop, and the paddle wheel would stop rotating.

**Figure 12** also shows an electric current doing work by lighting a lightbulb. Just as the water current stops flowing if there is no longer a closed loop to flow through, the electric current stops if there is no longer a closed path to follow. A closed path that electric current follows is a **circuit**. If the circuit in **Figure 12** is broken by removing the battery, or the light bulb, or one of the wires, current will not flow.

## Batteries

In order to keep water flowing continually in the water circuit in **Figure 12**, a pump is used to provide a pressure difference. In a similar way, to keep an electric current continually flowing in the electric circuit in **Figure 12**, a voltage difference needs to be maintained in the circuit. A battery can provide the voltage difference that is needed to keep current flowing in a circuit. Current flows as long as there is a closed path that connects one battery terminal to the other battery terminal.

## Mini LAB

### Investigating Battery Addition

#### Procedure

1. Make a circuit by using wire to link two bulbs and one D-cell battery in a loop. Observe the brightness of the bulbs.
2. Assemble a new circuit by linking two bulbs and two D-cell batteries in a loop. Observe the brightness of the bulbs.

#### Analysis

1. What is the voltage difference of each D cell? Add them together to find the total voltage difference for the circuit you tested in step 2.
2. Assuming that a brighter bulb indicates a greater current, what can you conclude about the relationship between the voltage difference and current?

**Dry-Cell Batteries** You probably are most familiar with dry-cell batteries. A cell consists of two electrodes surrounded by a material called an electrolyte. The electrolyte enables charges to move from one electrode to the other. Look at the dry cell shown in **Figure 13**. One electrode is the carbon rod, and the other is the zinc container. The electrolyte is a moist paste containing several chemicals. The cell is called a dry cell because the electrolyte is a moist paste, and not a liquid solution.



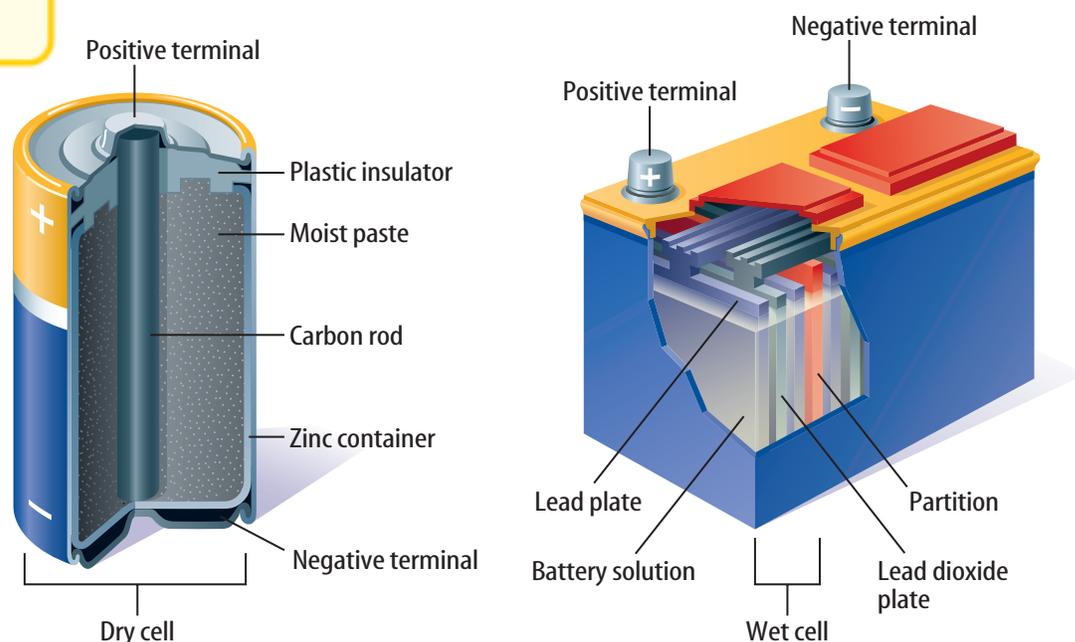
When the two terminals of a dry-cell battery are connected in a circuit, such as in a flashlight, a reaction involving zinc and several chemicals in the paste occurs. Electrons are transferred between some of the compounds in this chemical reaction. As a result, the carbon rod becomes positive, forming the positive (+) terminal. Electrons accumulate on the zinc, making it the negative (-) terminal.

The voltage difference between these two terminals causes current to flow through a closed circuit. You make a battery when you connect two or more cells together to produce a higher voltage difference.

**Wet-Cell Batteries** Another commonly used type of battery is the wet-cell battery. A wet cell, like the one shown in **Figure 13**, contains two connected plates made of different metals or metallic compounds in a conducting solution. A wet-cell battery contains several wet cells connected together.

**Figure 13** Chemical reactions in batteries produce a voltage difference between the positive and negative terminals.

**Identify** when these chemical reactions occur.



In this dry cell, chemical reactions in the moist paste transfer electrons to the zinc container.

In this wet cell, chemical reactions transfer electrons from the lead plates to the lead dioxide plates.

**Lead-Acid Batteries** Most car batteries are lead-acid batteries, like the wet-cell battery shown in **Figure 13**. A lead-acid battery contains a series of six wet cells made up of lead and lead dioxide plates in a sulfuric acid solution. The chemical reaction in each cell provides a voltage difference of about 2 V, giving a total voltage difference of 12 V. As a car is driven, the alternator recharges the battery by sending current through the battery in the opposite direction to reverse the chemical reaction.

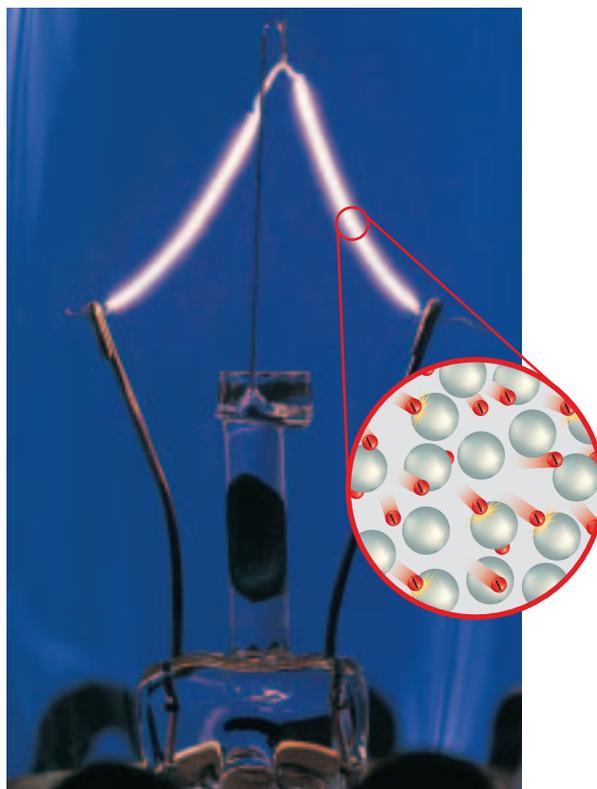
A voltage difference is provided at electrical outlets, such as a wall socket. This voltage difference usually is higher than the voltage difference provided by batteries. Most types of household devices are designed to use the voltage difference supplied by a wall socket. In the United States, the voltage difference across the two holes in a wall socket is usually 120 V. Some wall sockets supply 240 V, which is required by appliances such as electric ranges and electric clothes dryers.

## Resistance

Flashlights use dry-cell batteries to provide the electric current that lights a lightbulb. What makes a lightbulb glow? Look at the lightbulb in **Figure 14**. Part of the circuit through the bulb is a thin wire called a filament. As the electrons flow through the filament, they bump into the metal atoms that make up the filament. In these collisions, some of the electrical energy of the electrons is converted into thermal energy. Eventually, the metal filament becomes hot enough to glow, producing radiant energy that can light up a dark room.

**Resisting the Flow of Current** Electric current loses energy as it moves through the filament because the filament resists the flow of electrons. **Resistance** is the tendency for a material to oppose the flow of electrons, changing electrical energy into thermal energy and light. With the exception of some substances that become superconductors at low temperatures, all materials have some electrical resistance. Electrical conductors have much less resistance than insulators. Resistance is measured in ohms ( $\Omega$ ).

Copper is an excellent conductor and has low resistance to the flow of electrons. Copper is used in household wiring because only a small amount of electrical energy is converted to thermal energy as current flows in copper wires.



**Figure 14** As electrons move through the filament in a lightbulb, they bump into metal atoms. Due to the collisions, the metal heats up and starts to glow.

**Describe** the energy conversions that occur in a lightbulb filament.

**Temperature, Length, and Thickness** The electric resistance of most materials usually increases as the temperature of the material increases. The resistance of an object such as a wire also depends on the length and diameter of the wire. The resistance of a wire, or any conductor, increases as the wire becomes longer. The resistance also increases as the wire becomes thinner.

In a 60 watt lightbulb, the filament is a piece of tungsten wire made into a short coil a few cm long. The uncoiled wire is about 2 m long and only about 0.25 mm thick. Even though tungsten metal is a good conductor, by making the wire thin and long, the resistance of the filament is made large enough to cause the bulb to glow.

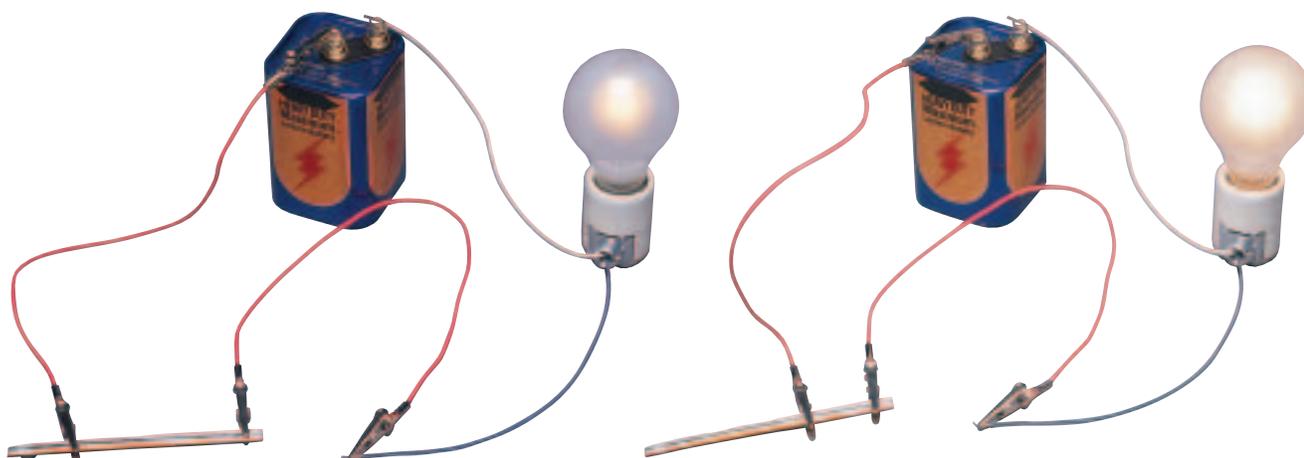
 **Reading Check** *How does changing the length and thickness of a wire affect its resistance?*

## The Current in a Simple Circuit

A simple electric circuit contains a source of voltage difference, such as a battery, a device, such as lightbulb, that has resistance, and conductors that connect the device to the battery terminals. When the wires are connected to the battery terminals, current flows in the closed path. An example of a simple circuit is shown in **Figure 15**.

The voltage difference, current, and resistance in a circuit are related. If the voltage difference doesn't change, decreasing the resistance increases the current in the circuit, as shown in **Figure 15**. Also, if the resistance doesn't change, increasing the voltage difference increases the current.

**Figure 15** The amount of current flowing through a circuit is related to the amount of resistance in the circuit.



When the clips on the graphite rod are farther apart, the resistance of the rod in the circuit is larger. As a result, less current flows in the circuit and the lightbulb is dim.

When the clips on the graphite rod are closer together, the resistance of the rod in the circuit is less. As a result, more current flows in the circuit and the lightbulb is brighter.

**Ohm's Law** The relationship between voltage difference, current and resistance in a circuit is known as Ohm's law. According to **Ohm's law**, the current in a circuit equals the voltage difference divided by the resistance. If  $I$  stands for electric current, Ohm's law can be written as the following equation.

### Ohm's Law

$$\text{current (in amperes)} = \frac{\text{voltage difference (in volts)}}{\text{resistance (in ohms)}}$$

$$I = \frac{V}{R}$$

Ohm's law provides a way to measure the resistance of objects and materials. First the equation above is written as:

$$R = \frac{V}{I}$$

An object is connected to a source of voltage difference and the current flowing in the circuit is measured. The object's resistance then equals the voltage difference divided by the measured current.



### Current and the Human Body

When an electric shock occurs, an electric current moves through some part of the body. The damage caused by an electric shock depends on how large the current is. Research the effects of current on the human body. Make a table showing the effects on the body at different amounts of current.

## section 2 review

### Summary

#### Current and Voltage Difference

- Electric current is the net movement of electric charge in a single direction.
- A voltage difference is related to the force that causes charges to flow.
- A circuit is a closed, conducting path.

#### Batteries

- Chemical reactions in a battery produce a voltage difference between the positive and negative battery terminals.
- Two commonly used types of batteries are dry-cell batteries and wet-cell batteries.

#### Resistance and Ohm's Law

- Resistance is the tendency of a material to oppose the flow of electrons.
- Ohm's law relates the current,  $I$ , resistance,  $R$ , and voltage difference,  $V$ , in a circuit:

$$I = \frac{V}{R}$$

### Self Check

1. **Compare and contrast** a current traveling through a circuit with a static discharge.
2. **Explain** how a carbon-zinc dry cell produces a voltage difference between the positive and negative terminals.
3. **Identify** two ways to increase the current in a simple circuit.
4. **Compare and contrast** the flow of water in a pipe and the flow of electrons in a wire.
5. **Think Critically** Explain how the resistance of a lightbulb filament changes after the light has been turned on.

### Applying Math

6. **Calculate** the voltage difference in a circuit with a resistance of  $25 \Omega$  if the current in the circuit is  $0.5 \text{ A}$ .
7. **Calculate Resistance** A current of  $0.5 \text{ A}$  flows in a  $60\text{-W}$  lightbulb when the voltage difference between the ends of the filament is  $120 \text{ V}$ . What is the resistance of the filament?



# Electrical Energy

## Reading Guide

### What You'll Learn

- **Describe** the difference between series and parallel circuits.
- **Recognize** the function of circuit breakers and fuses.
- **Calculate** electrical power.
- **Calculate** the electrical energy used by a device.

### Why It's Important

When you use an electric appliance, such as a hair dryer or a toaster oven, you pay for the electrical energy you use.

### Review Vocabulary

**energy:** the ability to cause change

### New Vocabulary

- series circuit
- parallel circuit
- electrical power

## Series and Parallel Circuits

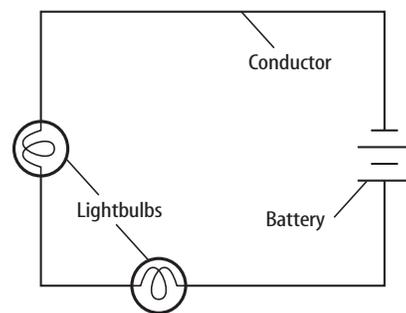
Look around. How many electrical devices such as lights, clocks, stereos, and televisions do you see that are plugged into electrical outlets? Circuits usually include three components. One is a source of voltage difference that can be provided by a battery or an electrical outlet. Another is one or more devices that use electrical energy. Circuits also include conductors such as wires that connect the devices to the source of voltage difference to form a closed path.

Think about using a hair dryer. The dryer must be plugged into an electrical outlet to operate. A generator at a power plant produces a voltage difference across the outlet, causing charges to move when the circuit is complete. The dryer and the circuit in the house contain conducting wires to carry current. The hair dryer turns the electrical energy into thermal energy and mechanical energy. When you unplug the hair dryer or turn off its switch, you open the circuit and break the path of the current. To use electrical energy, a complete circuit must be made. There are two kinds of circuits.

**Series Circuits** One kind of circuit is called a series circuit. In a **series circuit**, the current has only one loop to flow through, as shown in **Figure 16**. Series circuits are used in flashlights and some holiday lights.

**Figure 16** A series circuit provides only one path for the current to follow.

**Infer** What happens to the brightness of each bulb as more bulbs are added?



**Reading Check** How many loops are in a series circuit?



## INTEGRATE Career

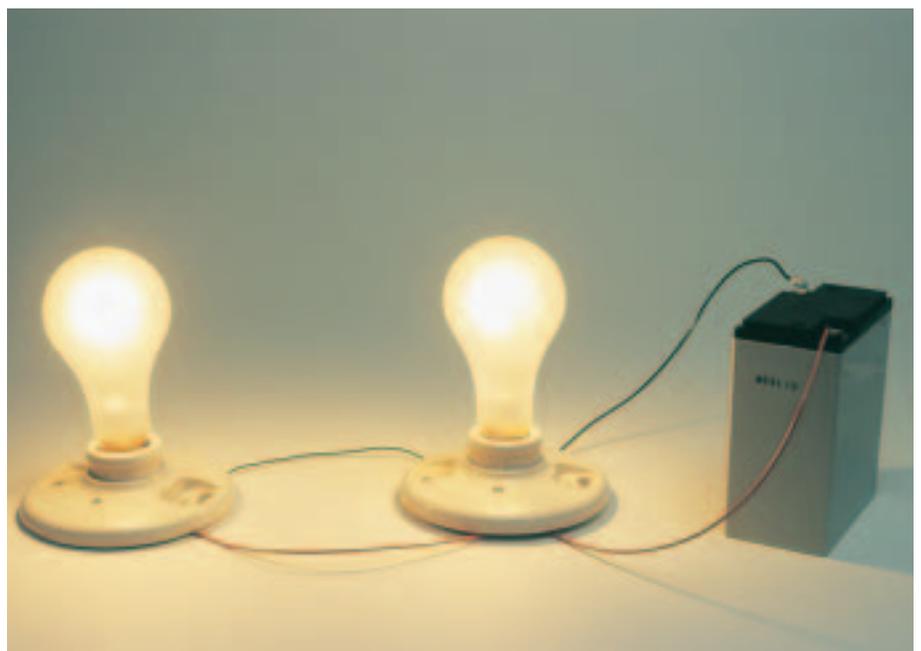
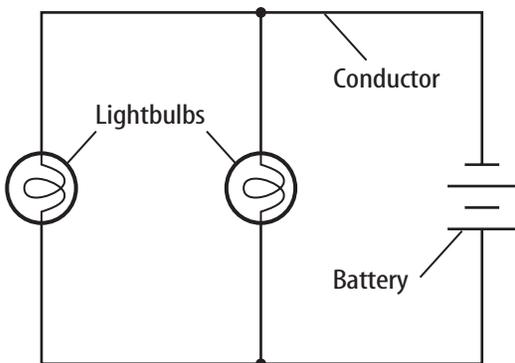
**Electrician** The installation of electrical wiring in any building usually requires an electrician. Electricians must have a thorough understanding of electricity. They also must constantly be aware of the safety issues involved in working with electricity. Research other skills that electricians must have.

**Open Circuit** If you have ever decorated a window or a tree with a string of lights, you might have had the frustrating experience of trying to find one burned-out bulb. How can one faulty bulb cause the whole string to go out? Because the parts of a series circuit are wired one after another, the amount of current is the same through every part. When any part of a series circuit is disconnected, no current flows through the circuit. This is called an open circuit. The burned-out bulb causes an open circuit in the string of lights.

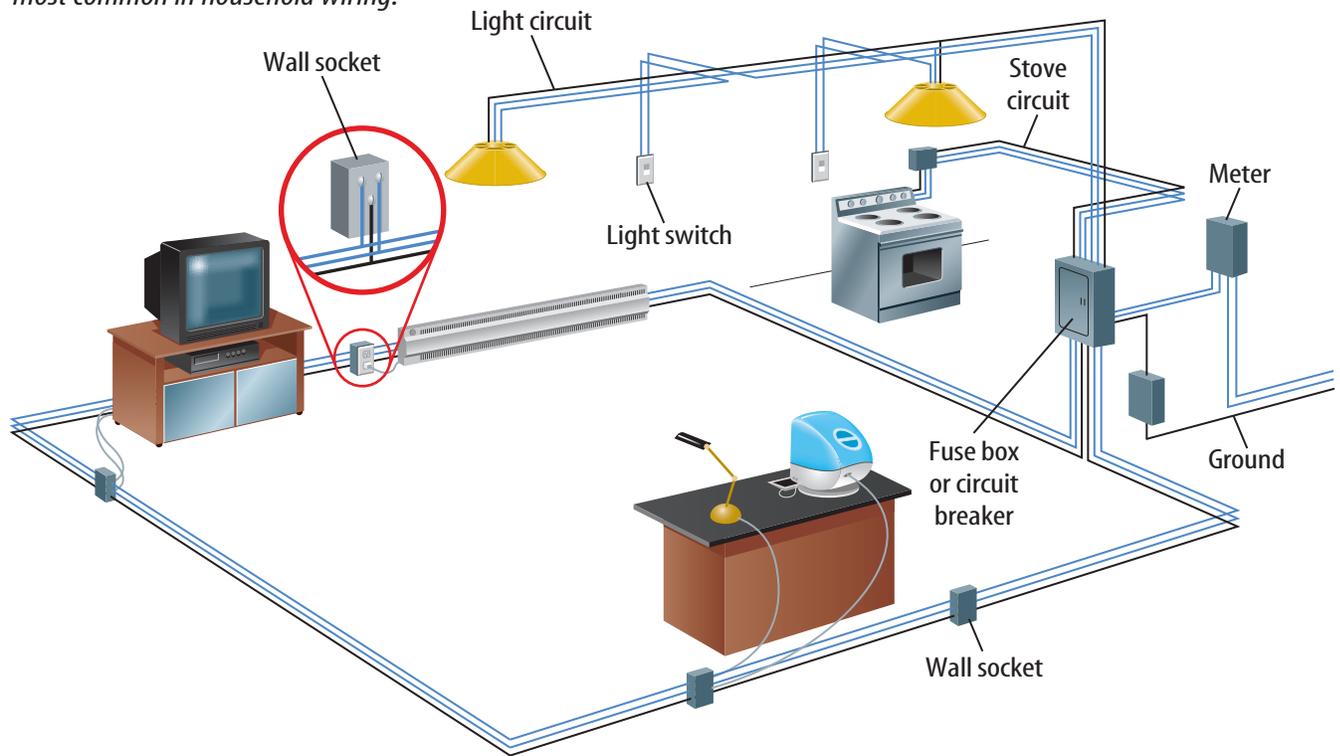
**Parallel Circuits** What would happen if your home were wired in a series circuit and you turned off one light? This would cause an open circuit, and all the other lights and appliances in your home would go out, too. This is why houses are wired with parallel circuits. **Parallel circuits** contain two or more branches for current to move through. Look at the parallel circuit in **Figure 17**. The current can flow through both or either of the branches. Because all branches connect the same two points of the circuit, the voltage difference is the same in each branch. Then, according to Ohm's law, more current flows through the branches that have lower resistance.

Parallel circuits have several advantages. When one branch of the circuit is opened, such as when you turn a light off, the current continues to flow through the other branches. Houses, automobiles, and most electrical systems use parallel wiring so individual parts can be turned off without affecting the entire circuit.

**Figure 17** In parallel circuits, the current follows more than one path. **Describe** how the voltage difference will compare in each branch.



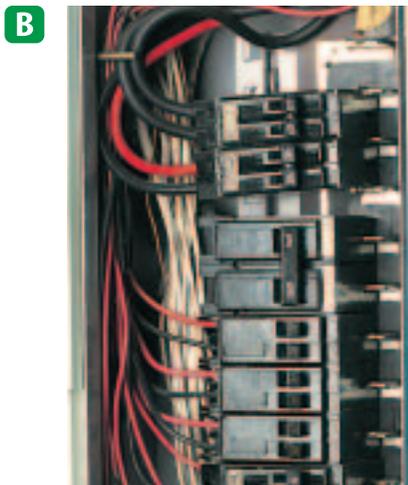
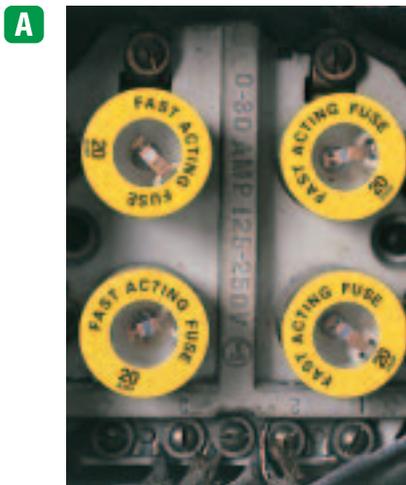
**Figure 18** The wiring in a house must allow for the individual use of various appliances and fixtures. **Identify** the type of circuit that is most common in household wiring.



## Household Circuits

Count how many different things in your home require electrical energy. You don't see the wires because most of them are hidden behind the walls, ceilings, and floors. This wiring is mostly a combination of parallel circuits connected in an organized and logical network. **Figure 18** shows how electrical energy enters a home and is distributed. In the United States, the voltage difference in most of the branches is 120 V. In some branches that are used for electric stoves or electric clothes dryers, the voltage difference is 240 V. The main switch and circuit breaker or fuse box serve as an electrical headquarters for your home. Parallel circuits branch out from the breaker or fuse box to wall sockets, major appliances, and lights.

In a house, many appliances draw current from the same circuit. If more appliances are connected, more current will flow through the wires. As the amount of current increases, so does the amount of heat produced in the wires. If the wires get too hot, the insulation can melt and the bare wires can cause a fire. To protect against overheating of the wires, all household circuits contain either a fuse or a circuit breaker.



**Figure 19** Two useful devices to prevent electric circuits from overheating are **A** fuses and **B** circuit breakers.

**Evaluate** which device, a fuse or a circuit breaker, would be more convenient to have in the home.

To enable current to flow again in the circuit, you must replace the blown fuse with a new one. However, before you replace the blown fuse, you should turn off or unplug some of the appliances. Too many appliances in use at the same time is the most likely cause for the overheating of the circuit.

**Circuit Breaker** A circuit breaker, shown in **Figure 19B**, is another device that prevents a circuit from overheating and causing a fire. A circuit breaker contains a piece of metal that bends when the current in it is so large that it gets hot. The bending causes a switch to flip and open the circuit, stopping the flow of current. Circuit breakers usually can be reset by pushing the switch to its “on” position. Again, before you reset a circuit breaker, you should turn off or unplug some of the appliances from the overloaded circuit. Otherwise, the circuit breaker will switch off again.

**Reading Check** What is the purpose of fuses and circuit breakers in household circuits?

## Electric Power

The reason that electricity is so useful is that electrical energy is converted easily to other types of energy. For example, electrical energy is converted to mechanical energy as the blades of a fan rotate to cool you. Electrical energy is converted to light energy in lightbulbs. A hair dryer changes electrical energy into thermal energy. The rate at which electrical energy is converted to another form of energy is the **electric power**.

The electric power used by appliances varies. Appliances often are labeled with a power rating that describes how much power the appliance uses, as shown in **Figure 20**. Appliances that have electric heating elements, such as ovens and hair dryers, usually use more electric power than other appliances.



**Figure 20** All appliances come with a power rating.

**Calculating Electric Power** The electric power used depends on the voltage difference and the current. Electric power can be calculated from the following equation.

### Electric Power Equation

$$\text{electric power (in watts)} = \text{current (in amperes)} \times \text{voltage difference (in volts)}$$
$$P = IV$$

The unit for power is the watt (W). Because the watt is a small unit of power, electric power is often expressed in kilowatts (kW). One kilowatt equals 1,000 watts.

## ELECTRIC POWER EQUATION

**Solve for Power** The current in a clothes dryer is 15 A when it is plugged into a 240-volt outlet. How much electric power does the clothes dryer use?

- This is what you know:** current:  $I = 15 \text{ A}$   
voltage difference:  $V = 240 \text{ V}$
- This is what you need to find:** power:  $P$
- Use this formula:**  $P = IV$
- Substitute:**  $P = (15)(240) = 3,600$   
the values of  $I$  and  $V$   
into the formula and multiply.
- Determine the units:** units of  $P = (\text{units of } I) \times (\text{units of } V)$   
 $= \text{amperes} \times \text{volts} = \text{watts}$

**Answer:** The power used by the dryer is 3,600 watts, which also equal to 3.6 kilowatts.

### Practice Problems

- A toaster oven is plugged into an outlet where the voltage difference is 120 V. How much power does the toaster oven use if the current in the oven is 10 A?
- A VCR that is not playing still uses 10.0 W of power. What is the current in the VCR if it is plugged into a 120-V outlet?
- A flashlight bulb uses 2.4 W of power when the current in the bulb is 0.8 A. What is the voltage difference supplied by the batteries?
- Challenge** A hair dryer uses 1.2 kW of power when it is plugged into a 120-V outlet and turned on. What is the current in the hair dryer?



For more practice problems, go to page 834, and visit [gpscience.com/extra\\_problems](http://gpscience.com/extra_problems).

### Topic: Energy

Visit [gpscience.com](http://gpscience.com) for Web links to information about the cost of electrical energy around the country.

**Activity** Using a blank map of the United States, create a key showing the relative energy costs in different states in different colors. With a partner, color in the states to create a visual map of energy costs. Give your map a title.

**Electrical Energy** Using electric power costs money. However, electric companies charge by the amount of electrical energy used, rather than by the electric power used. Electrical energy usually is measured in units of kilowatt hours (kWh) and can be calculated from this equation:

#### Electric Energy Equation

$$\text{electrical energy (in kWh)} = \text{electric power (in kW)} \times \text{time (in hours)}$$

$$E = Pt$$

In the above equation, electric power is in units of kW and the time is the number of hours that the electric power is used.

## ELECTRICAL ENERGY EQUATION

**Solve for Electrical Energy** A microwave oven with a power rating of 1,200 W is used for 0.25 h. How much electrical energy is used by the microwave?

- 1 **This is what you know:** electric power used:  $P = 1,200 \text{ W} = 1.2 \text{ kW}$   
time:  $t = 0.25 \text{ h}$
- 2 **This is what you need to find:** electrical energy used:  $E$
- 3 **Use this formula:**  $E = Pt$
- 4 **Substitute:**  $E = (1.2)(0.25) = 0.30$   
the values of  $P$  and  $t$   
into the formula and multiply.
- 5 **Determine the units:** units of  $E = (\text{units of } P) \times (\text{units of } t)$   
 $= \text{kW} \times \text{h} = \text{kWh}$

**Answer:** The electrical energy used is 0.30 kWh.

### Practice Problems

1. A refrigerator operates on average for 10.0 h a day. If the power rating of the refrigerator is 700 W, how much electrical energy does the refrigerator use in one day?
2. A TV with a power rating of 200 W uses 0.8 kWh of electrical energy in one day. For how many hours was the TV on during this day?
3. An electric dryer is operated for 0.75 h and uses 3.0 kWh of electrical energy. What is the power rating of the clothes dryer?
4. **Challenge** An electric light is plugged into a 120-V outlet. If the current in the bulb is 0.5 A, how much electrical energy is used by the bulb in 15 minutes?

## The Cost of Using Electrical Energy

The cost of using the appliance can be computed by multiplying the electrical energy used by the amount the power company charges for each kWh. For example, if a 100-W lightbulb is left on for 5 h, the amount of electrical energy used is

$$E = Pt = (0.1 \text{ kW}) (5 \text{ h}) = 0.5 \text{ kWh}$$

If the power company charges \$0.10 per kWh, the cost of using the bulb for 5 h is

$$\begin{aligned} \text{cost} &= (\text{kWh used}) (\text{cost per kWh}) \\ &= (0.5 \text{ kWh}) (\$0.10/\text{kWh}) = \$0.05 \end{aligned}$$

The cost of using some household appliances is given in **Table 1**, where the cost per kWh is assumed to be \$0.09/kWh.

**Table 1 Cost of Using Home Appliances**

| Appliance        | Hair Dryer | Stereo | Color Television |
|------------------|------------|--------|------------------|
| Power rating     | 1,000      | 100    | 200              |
| Hours used daily | 0.25       | 2.0    | 4.0              |
| kWh used monthly | 7.5        | 6.0    | 24.0             |
| Cost per kWh     | \$0.09     | \$0.09 | \$0.09           |
| Monthly cost     | \$0.68     | \$0.54 | \$2.16           |

## section 3 review

### Summary

#### Series and Parallel Circuits

- A series circuit has only one path that current can flow in.
- A parallel circuit has two or more branches that current can flow in.
- Household wiring usually consists of a number of connected parallel circuits.
- Fuses and circuit breakers are used to prevent wires from overheating when the current flowing in the wires becomes too large.

#### Electric Power

- Electric power is the rate at which electrical energy is converted into other forms of energy.
- Electric power can be calculated by multiplying the current by the voltage difference:

$$P = IV$$

#### Electrical Energy

- The electrical energy used can be calculated by multiplying the power by the time:

$$E = Pt$$

- Electric power companies charge customers for the amount of electrical energy they use.

### Checking Concepts

1. **Explain** how electric power and electrical energy are related.
2. **Discuss** why fuses and circuit breakers are used in household circuits.
3. **Explain** what determines the current in each branch of a parallel circuit.
4. **Explain** whether or not a fuse or circuit breaker should be connected in parallel to the circuit it is protecting.
5. **Think Critically** A parallel circuit consisting of four branches is connected to a battery. Explain how the amount of current that flows out of the battery is related to amount of current in the branches of the circuit.

### Applying Math

6. **Calculate** the current flowing into a desktop computer plugged into a 120-V outlet if the power used is 180 W.
7. **Calculate Electric Power** A circuit breaker is tripped when the current in the circuit is greater than 15 A. If the voltage difference is 120 V, what is the power being used when the circuit breaker is tripped?
8. **Calculate** the monthly cost of using a 700-W refrigerator that runs for 10 h a day if the cost per kWh is \$0.09.

# Comparing Series and Parallel Circuits

## Goals

- **Design** and construct series and parallel circuits.
- **Compare** and contrast the behaviors of series and parallel circuits.

## Possible Materials

6-V dry-cell battery  
small lights with sockets (3)  
aluminum foil  
paper clips  
tape  
scissors  
paper

## Safety Precautions



Some parts of circuits can become hot. Do not leave the battery connected or the circuit closed for more than a few seconds at a time. Never connect the positive and negative terminals of the dry-cell battery directly without including at least one bulb in the circuit.

## Real-World Question

Imagine what a bedroom might be like if it were wired in series. For an alarm clock to keep time and wake you in the morning, your lights and anything else that uses electricity would have to be on. Fortunately, most outlets in homes are wired in parallel circuits on separate branches of the main circuit. How do the behaviors of series and parallel circuits compare?



## Form a Hypothesis

Predict what will happen to the other bulbs when one bulb is unscrewed from a series circuit and from a parallel circuit. Explain your prediction. Also, form a hypothesis to explain in which circuit the lights shine the brightest.

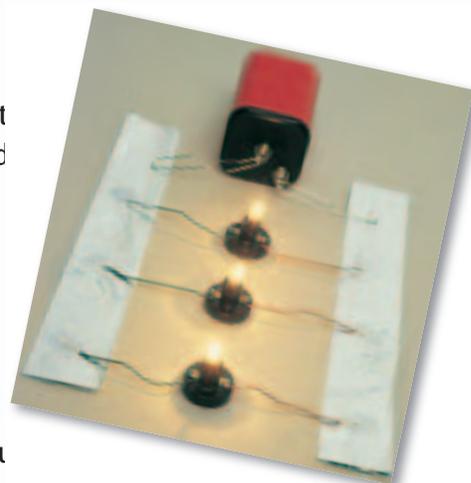


## Using Scientific Methods

### ▶ Test Your Hypothesis

#### Make a Plan

1. As a group, agree upon and write the hypothesis statement.
2. Work together determining and writing the steps you will take to test your hypothesis. Include a list of the materials you will need.
3. How will your circuits be arranged? On a piece of paper, draw a large parallel circuit of three lights and the dry-cell battery as shown. On the other side, draw another circuit with the three bulbs arranged in series.
4. Make conducting wires by taping a 30-cm piece of transparent tape to a sheet of aluminum foil and folding the foil over twice to cover the tape. Cut these to any length that works in your design.



#### Follow Your Plan

1. Make sure your teacher approves your plan before you start.
2. Carry out the experiment. **WARNING:** Leave the circuit on for only a few seconds at a time to avoid overheating.
3. As you do the experiment, record your predictions and your observations in your Science Journal.

### ▶ Analyze Your Data

1. **Predict** what will happen in the series circuit when a bulb is unscrewed at one end. What will happen in the parallel circuit?
2. **Compare** the brightness of the lights in the different circuits. Explain.
3. **Predict** what happens to the brightness of the bulbs in the series circuit if you complete it with two bulbs instead of three bulbs. Test it. How does this demonstrate Ohm's law?

### ▶ Conclude and Apply

1. Did the results support your hypothesis? Explain by using your observations.
2. Where in the parallel circuit would you place a switch to control all three lights? Where would you place a switch to control only one light? Test it.

#### Communicating Your Data

**Prepare** a poster to highlight the differences between a parallel and a series circuit. Include possible practical applications of both types of circuits. **For more help, refer to the Science Skill Handbook.**

## Invisible Man

by Ralph Ellison

I am an invisible man. No, I am not a spook like those who haunted Edgar Allen Poe; nor am I one of your Hollywood-movie ectoplasms.<sup>1</sup> A am a man of substance, of flesh and bone, fiber and liquids—and I might even be said to possess a mind. I am invisible, understand, simply because people refuse to see me. . . . Nor is my invisibility exactly a matter of biochemical accident to my epidermis.<sup>2</sup> That invisibility to which I refer occurs because of a peculiar disposition . . . of those with whom I come in contact. . . .

. . . . Now don't jump to the conclusion that because I call my home a "hole" it is damp and cold like a grave. . . . Mine is a warm hole.

My hole is warm and full of light. Yes, *full of light*. I doubt if there is a brighter spot in all New York than this hole of mine. . . . Perhaps you'll think it strange that an invisible man should need light, desire light, love light. Because maybe it is exactly because I *am invisible*. Light confirms my reality, gives birth to my form. . . . I myself, after existing some twenty years, did not become alive until I discovered my invisibility.

. . . In my hole in the basement there are exactly 1,369 lights. I've wired the entire ceiling, every inch of it. . . . Though invisible, I am in the great American tradition of tinkers. That makes me kin to Ford, Edison and Franklin.



Ralph Ellison

1 The outer layer of a part of the cell.

2 The outer layer of skin.

### Understanding Literature

**Prologue** A prologue is an introduction to a novel, play, or other work of literature. Often a prologue contains useful information about events to come in the story. Foreshadowing is the use of clues by the author to prepare readers for future events or recurring themes.

### Respond to the Reading

1. What clues does the narrator give that he is not really invisible?
2. Why does the narrator believe he is in the "great American tradition of tinkers"?
3. **Linking Science and Writing** Write a prologue to a make-believe book describing Edison's invention of the lightbulb. Recall that a prologue is not a summary of the book. Rather, it can state general themes that the work of literature will address or set the stage or describe the setting of the story.



If all 1,369 lightbulbs were all wired together in a series circuit, the electrical resistance in the circuit would be high. By Ohm's law, the current in the circuit would be low and the bulbs wouldn't glow. If all the bulbs were wired in a parallel circuit, so much current would flow in the circuit that the connecting wires would melt. For the bulbs to light, the narrator must have wired them in many independent circuits.

## Reviewing Main Ideas

## Section 1 Electric Charge

1. There are two types of electric charge—positive charge and negative charge.
2. Electric charges exert forces on each other. Like charges repel and unlike charges attract.
3. Electric charges can be transferred from one object to another, but cannot be created or destroyed.
4. Electrons can move easily in an electrical conductor. Electrons do not move easily in an insulator.
5. Objects can be charged by contact or by induction. Charging by induction occurs when a charged object is brought near an electrically neutral object.



4. Electrical resistance is the tendency of a material to oppose the flow of electric current.
5. In an electric circuit, the voltage difference, current, and resistance are related by Ohm's law:

$$I = \frac{V}{R}$$

## Section 3 Electrical Energy

1. Current has only one path in a series circuit and more than one path in a parallel circuit.
2. Circuit breakers and fuses prevent excessive current from flowing in a circuit.
3. Electrical power is the rate at which electrical energy is used, and can be calculated from  $P = IV$ .
4. The electrical energy used by a device can be calculated from the equation  $E = Pt$ .

## Section 2 Electric Current

1. Electric current is the net movement of electric charges in a single direction. A voltage difference causes an electric current to flow.
2. A circuit is a closed path along which charges can move. Current will flow continually only along a circuit that is unbroken.
3. Chemical reactions in a battery produce a voltage difference between the positive and negative terminals of the battery.



**FOLDABLES™** Use the Foldable you made at the beginning of the chapter to help you review electric charge, electric current, and electrical energy.

## Using Vocabulary

charging by contact p. 195    law of conservation of charge p. 193  
 charging by induction p. 196    Ohm's law p. 205  
 circuit p. 201    parallel circuit p. 208  
 conductor p. 195    resistance p. 203  
 electric current p. 200    series circuit p. 207  
 electrical power p. 210    static electricity p. 192  
 insulator p. 195    voltage difference p. 200

Complete each statement using a word(s) from the vocabulary list above.

- A(n) \_\_\_\_\_ is a circuit with only one path for current to follow.
- An accumulation of excess electric charge is \_\_\_\_\_.
- The electric force that makes current flow in a circuit is related to the \_\_\_\_\_.
- According to \_\_\_\_\_, electric charge cannot be created or destroyed.
- \_\_\_\_\_ is the result of electrons colliding with atoms as current flows in a material.
- Charging a balloon by rubbing it on wool is an example of \_\_\_\_\_.
- The electric force between two charged objects depends on which of the following?
  - their masses and their separation
  - their speeds
  - their charge and their separation
  - their masses and their charge
- An object becomes positively charged when which of the following occurs?
  - loses electrons
  - loses protons
  - gains electrons
  - gains neutrons
- Which of the following does NOT provide a voltage difference in a circuit?
  - wet cell
  - wires
  - electrical outlet
  - dry cell
- A commonly used unit for electrical energy is which of the following?
  - kilowatt-hour
  - ampere
  - ohm
  - newton
- Which of the following is the rate at which appliances use electrical energy?
  - power
  - current
  - resistance
  - speed

## Interpreting Graphics

Use the table below to answer question 14.

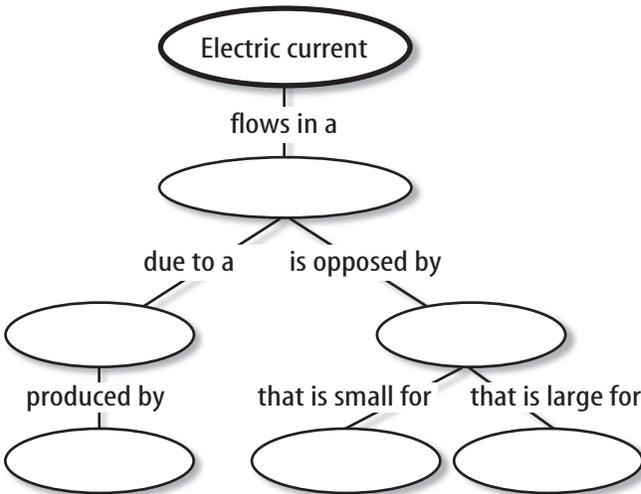
| Current in Electric Circuits |             |
|------------------------------|-------------|
| Circuit                      | Current (A) |
| A                            | 2.3         |
| B                            | 0.6         |
| C                            | 0.2         |
| D                            | 1.8         |

## Checking Concepts

Choose the word or phrase that best answers the question.

- Which of the following is a conductor?
  - glass
  - wood
  - tungsten
  - plastic
- Resistance in wires causes electrical energy to be converted into which form of energy?
  - chemical energy
  - nuclear energy
  - thermal energy
  - sound
- The table shows the current in circuits that were each connected to a 6-V dry cell. Calculate the resistance of each circuit. Graph the current versus the resistance of each circuit. Describe the shape of the line on your graph.

15. Copy and complete the following concept map on electric current.



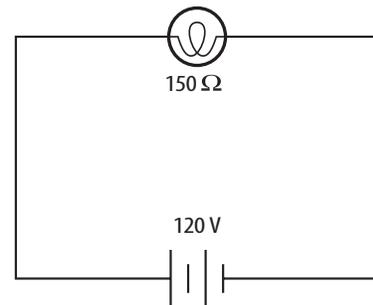
### Thinking Critically

16. **Identify and Manipulate Variables** Design an experiment to test the effect on current and voltage differences in a circuit when two identical batteries are connected in series. What is your hypothesis? What are the variables and controls?
17. **Explain** A metal rod is charged by induction when a negatively-charged plastic rod is brought nearby. Explain how the net charge on the metal rod has changed.
18. **Predict** You walk across a carpet on a dry day and touch a glass doorknob. Predict whether or not you would receive an electric shock. Explain your reasoning.
19. **Explain** The electric force between electric charges is much larger than the gravitational force between the charges. Why then is the gravitational force between Earth and the Moon much larger than the electric force between Earth and the Moon?

20. **Diagram** Draw a circuit diagram showing how a stereo, a TV, and a computer can be connected to a single source of voltage difference, such that turning off one appliance does not turn off all the others. Include a circuit breaker in your diagram that will protect all the appliances.

### Applying Math

21. **Calculate Current** Using the information in the circuit diagram below, compute the current flowing in the circuit.



22. **Calculate Current** A toy car with a resistance of  $20 \Omega$  is connected to a 3-V battery. How much current flows in the car?
23. **Calculate Electrical Energy** The current flowing in an appliance connected to a 120-V source is 2 A. How many kilowatt-hours of electrical energy does the appliance use in 4 h?
24. **Calculate Electrical Energy Cost** A self-cleaning oven uses 5,400 W when cleaning the oven. If it takes 1.5 h to clean, how many kilowatt-hours of electricity are used? At a cost of \$0.09 per kWh, what does it cost to clean the oven?
25. **Calculate Power** A calculator uses a 9-V battery and draws 0.1 A of current. How much power does it use?

## Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

- Which of the following is true about two adjacent electric charges?
  - If both are positive, they attract.
  - If both are negative, they attract.
  - If one is positive and one is negative, they attract.
  - If one is positive and one is negative, they repel.

The figure below shows a negatively charged electroscope. Use the figure to answer questions 2 and 3.



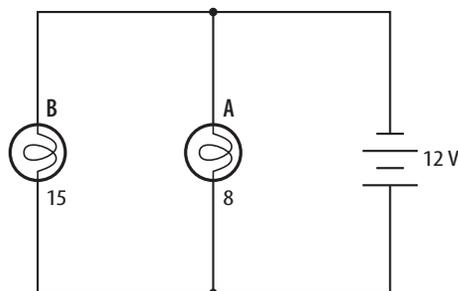
- If a negatively-charged rod is brought close to, but not touching, the knob, the two leaves will
  - move closer together.
  - move farther apart.
  - not move at all.
  - become positively charged.
- If a positively charged rod touches the knob, the two leaves will
  - move closer together.
  - move farther apart.
  - not move at all.
  - become positively charged.
- Which of these is the SI unit of current?
 

|         |           |
|---------|-----------|
| A. volt | C. ampere |
| B. ohm  | D. watt   |
- A kilowatt-hour is a unit of
 

|                     |                |
|---------------------|----------------|
| A. power.           | C. current.    |
| B. electric energy. | D. resistance. |

- When two objects become charged by contact, which of the following is true?
  - The net charge on each object doesn't change.
  - Both become negatively charged.
  - Both become positively charged.
  - Electrons are transferred.
- When an object becomes charged by induction, which of the following best describes the net charge on the object?
  - The net charge increases.
  - The net charge decreases.
  - The object is electrically neutral.
  - The net charge is negative.

Use the figure below to answer questions 8, 9, and 10.



- Which of the following is the same for each lightbulb?
  - current in the filament
  - voltage difference
  - electric resistance
  - charging by induction
- Which of the following is the current that flows through lightbulb B?
 

|           |          |
|-----------|----------|
| A. 1.25 A | C. 0.8 A |
| B. 0.67 A | D. 1.5 A |
- Which of the following is the electric power used by lightbulb A?
 

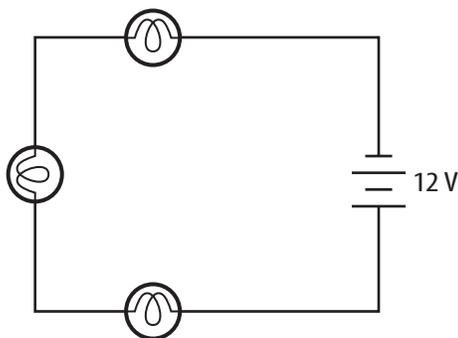
|         |         |
|---------|---------|
| A. 8 W  | C. 12 W |
| B. 18 W | D. 15 W |

## Part 2 Short Response/Grid In

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

- The current flowing through a lightbulb is 2.5 A. The lamp is connected to a battery supplying a voltage difference of 12 V. What is the power used by the lightbulb?
- A person spends four hours a day in a room, but leaves a 100-W lightbulb burning 24 hours a day. How much energy would be saved if the bulb burned for only the four hours the person was in the room?

Use the figure below to answer questions 13, 14, and 15.



- If the current in the circuit is 1.0 A, what is the total resistance of the circuit?
- If the current in the circuit is 1.0 A, how much electrical energy is used by the circuit in 2.5 h?
- How does the current in the circuit change if one of the lightbulbs is removed and the circuit is reconnected?
- Two balloons are rubbed with a piece of wool. Describe what happens as the balloons are brought close together.
- Calculate the cost of the electrical energy used by a TV for 30 days if the TV is on for four hours a day and the TV uses 250 W. Assume that the cost of electrical energy is \$0.10 per kWh.

## Part 3 Open Ended

Record your answers on a sheet of paper.

- Explain how a refrigerator with a power rating of 650 W can use more electrical energy in a day than a hair dryer with a power rating of 1,000 W.
- Two copper wires have the same length and the same temperature. However, the electric resistance of wire A is twice as large as the resistance of wire B. Explain how wire A and wire B are different.
- A rubber rod rubbed on hair becomes negatively charged. A glass rod rubbed with a piece of silk becomes positively charged. Suppose the charged rubber rod is suspended so it is free to rotate. Describe how the rubber rod moves as the piece of silk is brought close to it.

Use the table below to answer question 21.

| Resistance of Copper Wire |                         |
|---------------------------|-------------------------|
| Length (m)                | Resistance ( $\Omega$ ) |
| 10                        | 0.8                     |
| 20                        | 1.6                     |
| 25                        | 2.0                     |
| 30                        | 2.4                     |

- Suppose you were asked to estimate the resistance of a 5-m length of wire based on data in the table. What additional information would be needed to make your estimate more accurate?
- The filament in a 75-W lightbulb has a smaller electric resistance than the filament in a 40-W lightbulb. Describe two ways the filament in the 75-W bulb could be different from the filament in the 40-W lightbulb.