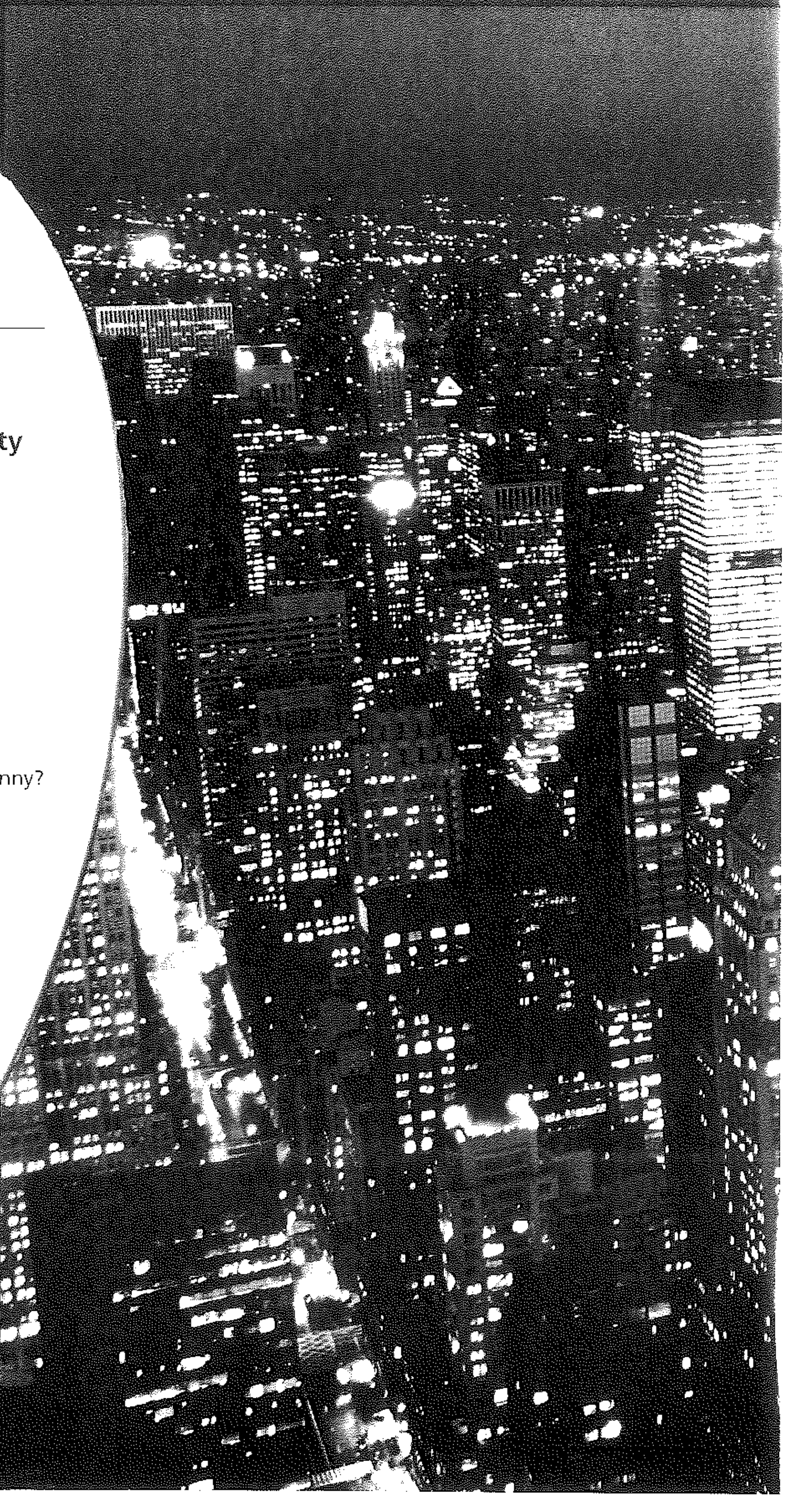
Chapter 20 Electricity

The BIG Idea

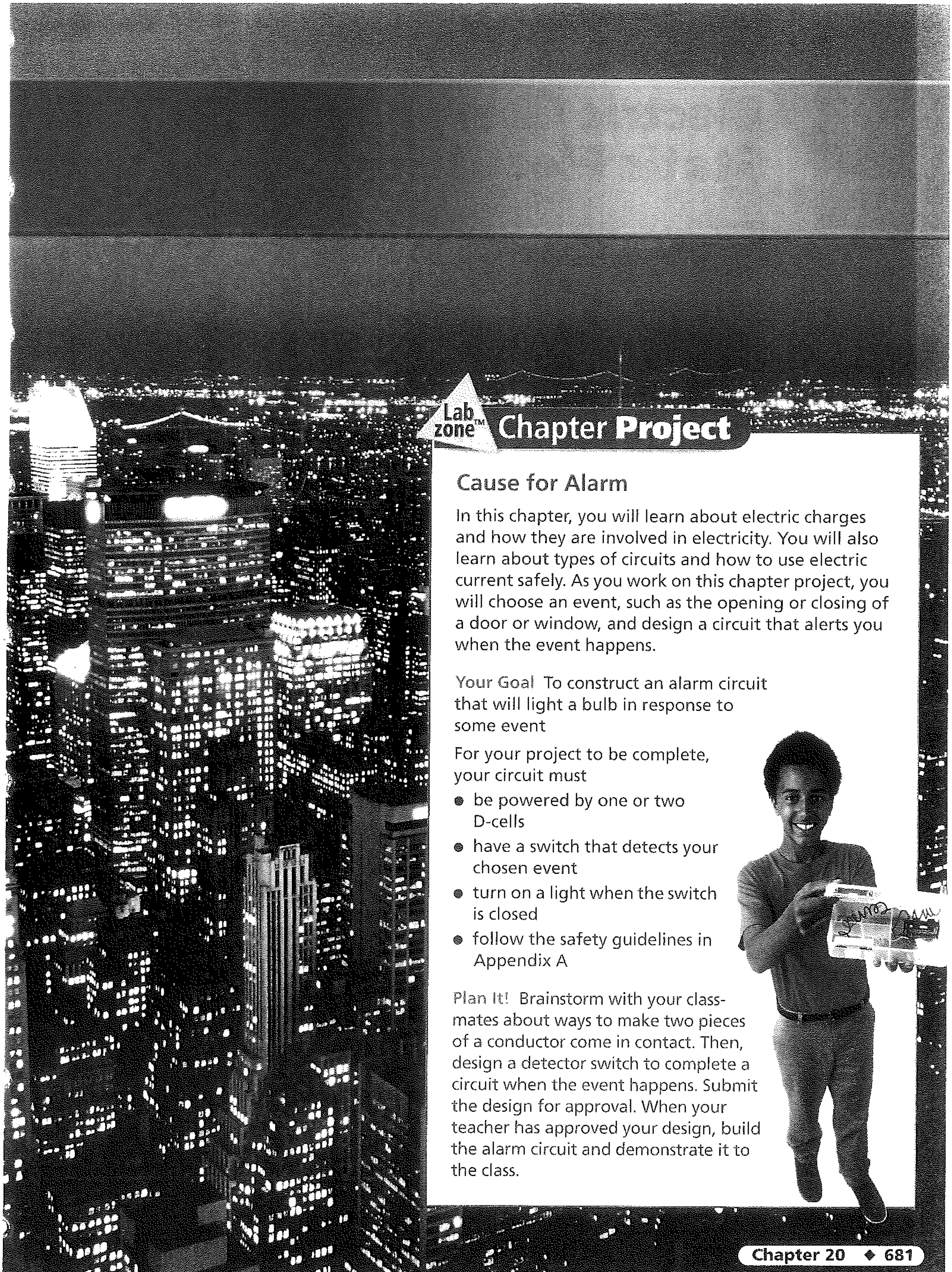
Transfer of Energy

What is electric current?

Chapter Preview



Electric lights sparkle in New York City at night.



Lab zone™ **Chapter Project**

Cause for Alarm

In this chapter, you will learn about electric charges and how they are involved in electricity. You will also learn about types of circuits and how to use electric current safely. As you work on this chapter project, you will choose an event, such as the opening or closing of a door or window, and design a circuit that alerts you when the event happens.

Your Goal To construct an alarm circuit that will light a bulb in response to some event

For your project to be complete, your circuit must

- be powered by one or two D-cells
- have a switch that detects your chosen event
- turn on a light when the switch is closed
- follow the safety guidelines in Appendix A

Plan It! Brainstorm with your classmates about ways to make two pieces of a conductor come in contact. Then, design a detector switch to complete a circuit when the event happens. Submit the design for approval. When your teacher has approved your design, build the alarm circuit and demonstrate it to the class.

Section 1

Electric Charge and Static Electricity

Reading Preview

Key Concepts

- How do electric charges interact?
- What is an electric field?
- How does static electricity build up and transfer?

Key Terms

- electric force
- electric field
- static electricity
- conservation of charge
- friction
- conduction
- induction
- static discharge

Target Reading Skill

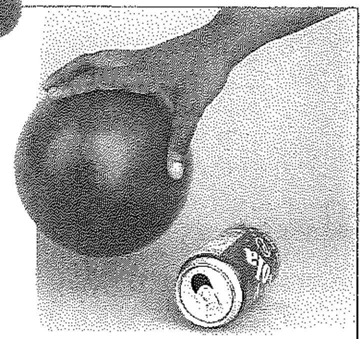
Previewing Visuals Before you read, preview Figure 4. Then write two questions that you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

Transferring Static Electricity

Q.	What are three ways static electricity can be transferred?
A.	
Q.	

Lab zone Discover Activity

Can You Move a Can Without Touching It?

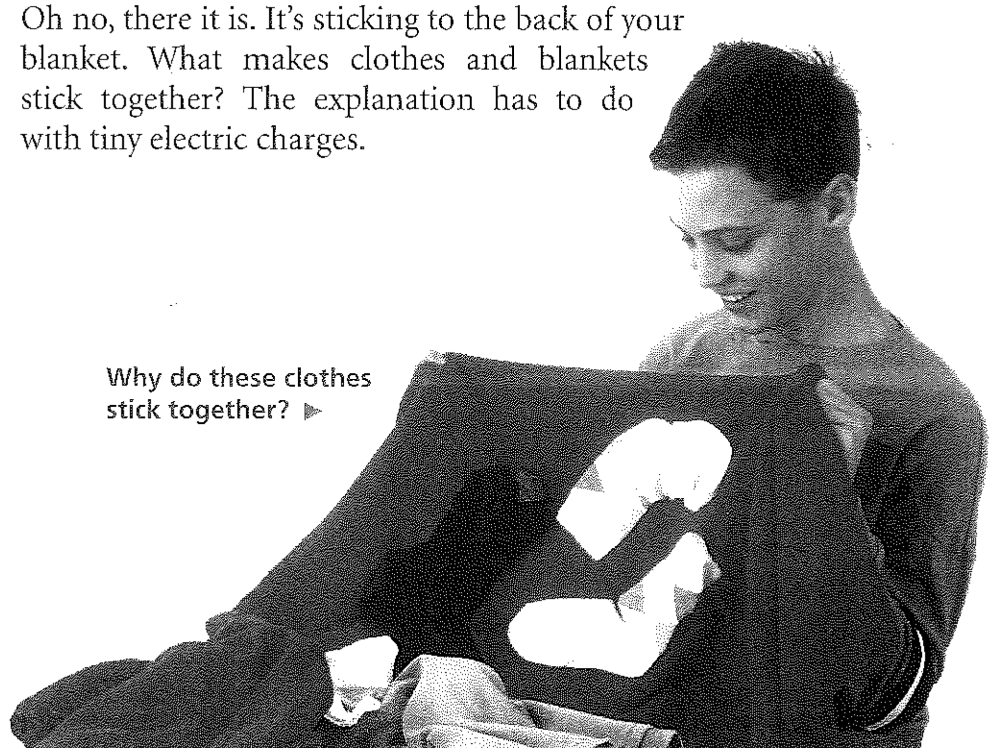


1. Place an empty aluminum can on its side on the floor.
2. Blow up a balloon. Then rub the balloon back and forth on your hair several times.
3. Hold the balloon about 2 to 3 centimeters away from the can.
4. Slowly move the balloon farther away from the can. Observe what happens.
5. Move the balloon to the other side of the can and observe what happens.

Think It Over

Inferring What happens to the can? What can you infer from your observation?

You're in a hurry to get dressed for school, but you can't find one of your socks. You quickly head for the pile of clean laundry. You've gone through everything, but where's your matching sock? The dryer couldn't have really destroyed it, could it? Oh no, there it is. It's sticking to the back of your blanket. What makes clothes and blankets stick together? The explanation has to do with tiny electric charges.



Why do these clothes stick together? ▶

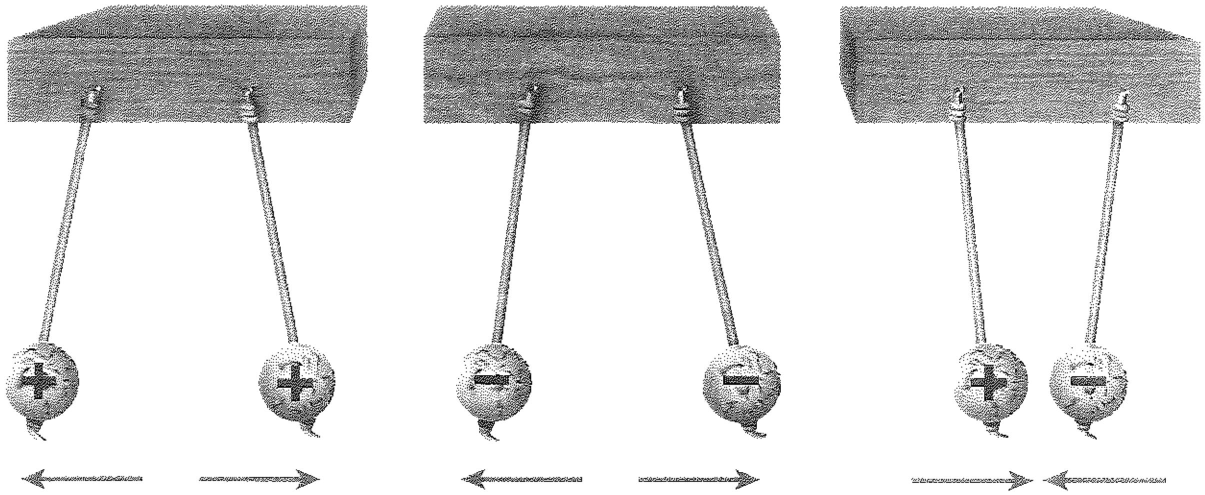


FIGURE 1
Repel or Attract?
The two types of charge, positive and negative, react to one another in specific ways.
Interpreting Diagrams *Which combinations of charges repel each other?*

Electric Charge

Recall that the charged parts of atoms are electrons and protons. When two protons come close together, they push one another apart. In other words, the protons repel each other. But if a proton and an electron come close together, they attract one another.

Why do protons repel protons but attract electrons? The reason is that they have different types of electric charge. Electric charge is a property of electrons and protons. Protons and electrons have opposite charges. The charge on a proton is called positive (+), and the charge on a electron is called negative (−). The names *positive* and *negative* were given to charges by Benjamin Franklin in the 1700s.

The two types of electric charges interact in specific ways, as you see in Figure 1. **Charges that are the same repel each other. Charges that are different attract each other.** Does this sound familiar to you? This rule is the same as the rule for interactions between magnetic poles. Recall that magnetic poles that are alike repel each other, and magnetic poles that are different attract each other. This interaction between magnetic poles is called magnetism. The interaction between electric charges is called electricity.

There is one important difference between electric charges and magnetic poles. Recall that magnetic poles cannot exist alone. Whenever there is a south pole, there is always a north pole. In contrast, electric charges can exist alone. In other words, a negative charge can exist without a positive charge.

Reading Checkpoint **What is one important difference between magnetism and electricity?**

Lab zone **Skills Activity**

Drawing Conclusions

1. Tear tissue paper into small pieces, or use a hole punch to cut circles.
2. Run a plastic comb through your hair several times.
3. Place the comb close to, but not touching, the tissue paper pieces. What do you observe?

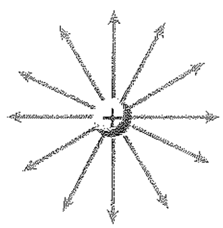
What can you conclude about the electric charges on the comb and the tissue paper?

FIGURE 2

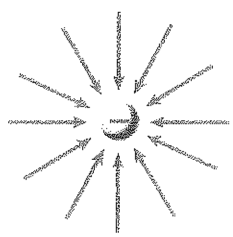
Electric Charges and Fields

The lines in each diagram represent an electric field. The stronger the field, the closer together the lines are.

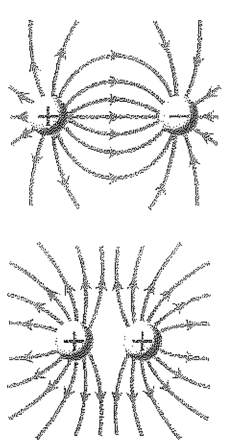
A The electric field around a positive charge points outward.



B The electric field around a negative charge points inward.



C The electric fields around charged particles are combined when they are brought near each other.



Electric Force

You may think of force as a push or pull on an object. For example, the force of gravity pulls objects toward the ground. You have learned that magnetic force is the attraction or repulsion between magnetic poles. In electricity, **electric force** is the attraction or repulsion between electric charges.

Electric Field Just as magnetic poles exert their forces over a distance, so do electric charges. Recall that a magnetic field extends around a magnet. Similarly, an **electric field** extends around a charged object. **An electric field is a region around a charged object where the object's electric force is exerted on other charged objects.**

When one charged object is placed in the electric field of another charged object, it is either pushed or pulled. It is pushed away if the two objects have the same charge. It is pulled toward the other charged object if their charges are different.

Electric Field Around a Single Charge An electric field is invisible, just like a magnetic field. You may recall using magnetic field lines to represent a magnetic field. In a similar way, you can use electric field lines to represent the electric field. Electric field lines are drawn with arrows to show the direction of the electric force. The electric force always points away from positive charges, as shown in Figure 2A. Notice in Figure 2B that the electric force always points toward negative charges.

The strength of an electric field is related to the distance from the charged object. The greater the distance, the weaker the electric field is. The strength of an electric field is represented by how close the electric field lines are to each other. The electric field is strongest where the lines are closest together. Since the strength of the electric field is greatest near the charged object, that's where the lines appear closest together. Farther from the charged object, the lines appear more spread out because the magnetic field is weaker.

Electric Field Around Multiple Charges When there are two or more charges, the shape of the electric field of each charge is altered. The electric fields of each individual charge combine by repelling or attracting. Figure 2C shows the interaction of the electric fields from two pairs of charges.

Reading Checkpoint **What is electric force?**

Static Electricity

Most objects normally have no overall charge, which means that they are neutral. Each atom has an equal number of protons and electrons. So each positive charge is balanced by a negative charge. As a result, there is no overall electric force on an atom.

Some objects, however, can become charged. Protons are bound tightly in the center of an atom, but electrons can sometimes leave their atoms. In materials such as silver, copper, gold, and aluminum, some electrons are held loosely by the atoms. These electrons can move to other atoms. As you see in Figure 3, an uncharged object becomes charged by gaining or losing electrons. If an object loses electrons, it is left with more protons than electrons. Therefore, the object has an overall positive charge. If an object gains electrons, it has more electrons than protons and has an overall negative charge.

The buildup of charges on an object is called **static electricity.** *Static* means "not moving or changing." **In static electricity, charges build up on an object, but they do not flow continuously.**

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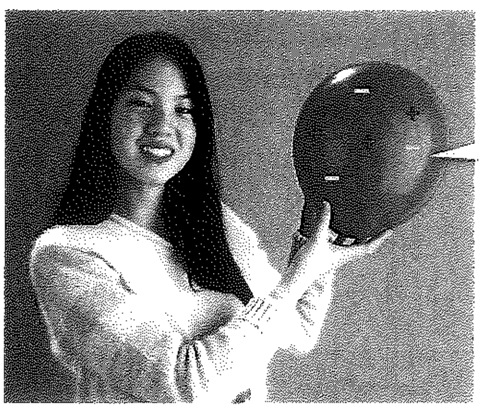
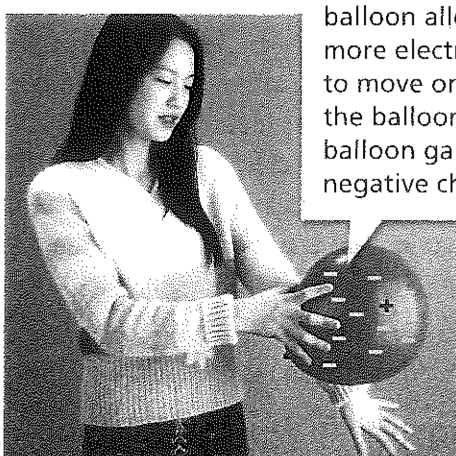
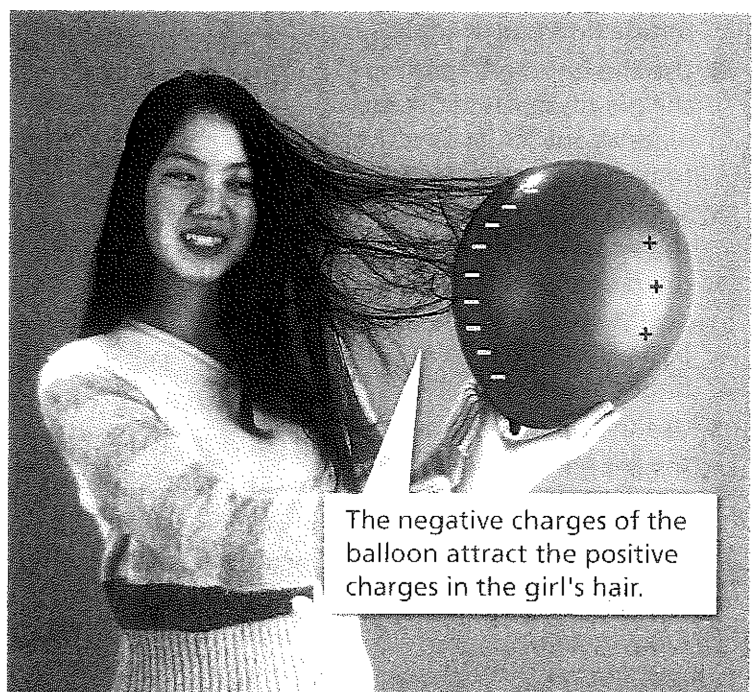
FIGURE 3
Charging by Friction
Rubbing two objects together may produce a buildup of static electricity.
Relating Cause and Effect *In what two ways can an uncharged object become charged?*







Transferring Charge

An object becomes charged only when electrons are transferred from one location to another. Charges are neither created nor destroyed. This is a rule known as the law of **conservation of charge.** If one object gives up electrons, another object gains those electrons. **There are three methods by which charges can be transferred to build up static electricity: charging by friction, by conduction, and by induction.**

Charging by Friction When two uncharged objects rub together, some electrons from one object can move onto the other object. The object that gains electrons becomes negatively charged, and the object that loses electrons becomes positively charged. Charging by **friction** is the transfer of electrons from one uncharged object to another by rubbing. In Figure 4, when the girl's socks rub the carpet, electrons move from the carpet onto her sock. This causes an overall negative charge on the sock. Clothing that sticks together when it is taken out of the dryer is another example of charging by friction.

Charging by Conduction When a charged object touches another object, electrons can be transferred between the objects. Electrons transfer from the object that has the more negative charge to the one that has the more positive charge. For example, a positively charged object will gain electrons when it touches an uncharged object. Charging by **conduction** is the transfer of electrons from a charged object to another object by direct contact. In Figure 4, charges are transferred from the girl's feet to the rest of her body because of charging by conduction.

Charging by Induction In charging by friction and by conduction, electrons are transferred when objects touch one another. In charging by induction, however, objects do not touch when the charges transfer. Charging by **induction** is the movement of electrons to one part of an object that is caused by the electric field of a second object. The electric field around the charged object attracts or repels electrons in the second object. In Figure 4, for example, the negative charges in the girl's fingertip produce an electric field that repels the electrons on the surface of the doorknob. The electrons on the doorknob move away from the finger. This movement produces an induced positive charge on the doorknob.

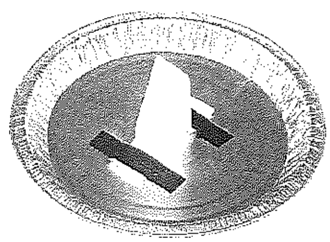
Reading Checkpoint **What is the difference between charging by induction and charging by conduction?**

Lab zone **Try This Activity**

Sparks Are Flying

Lightning is the result of static electricity. You can make your own lightning.

1. Cut a strip 3 cm wide from the middle of a foam plate. Fold the strip to form a W. Tape it to the center of an aluminum pie plate as a handle.

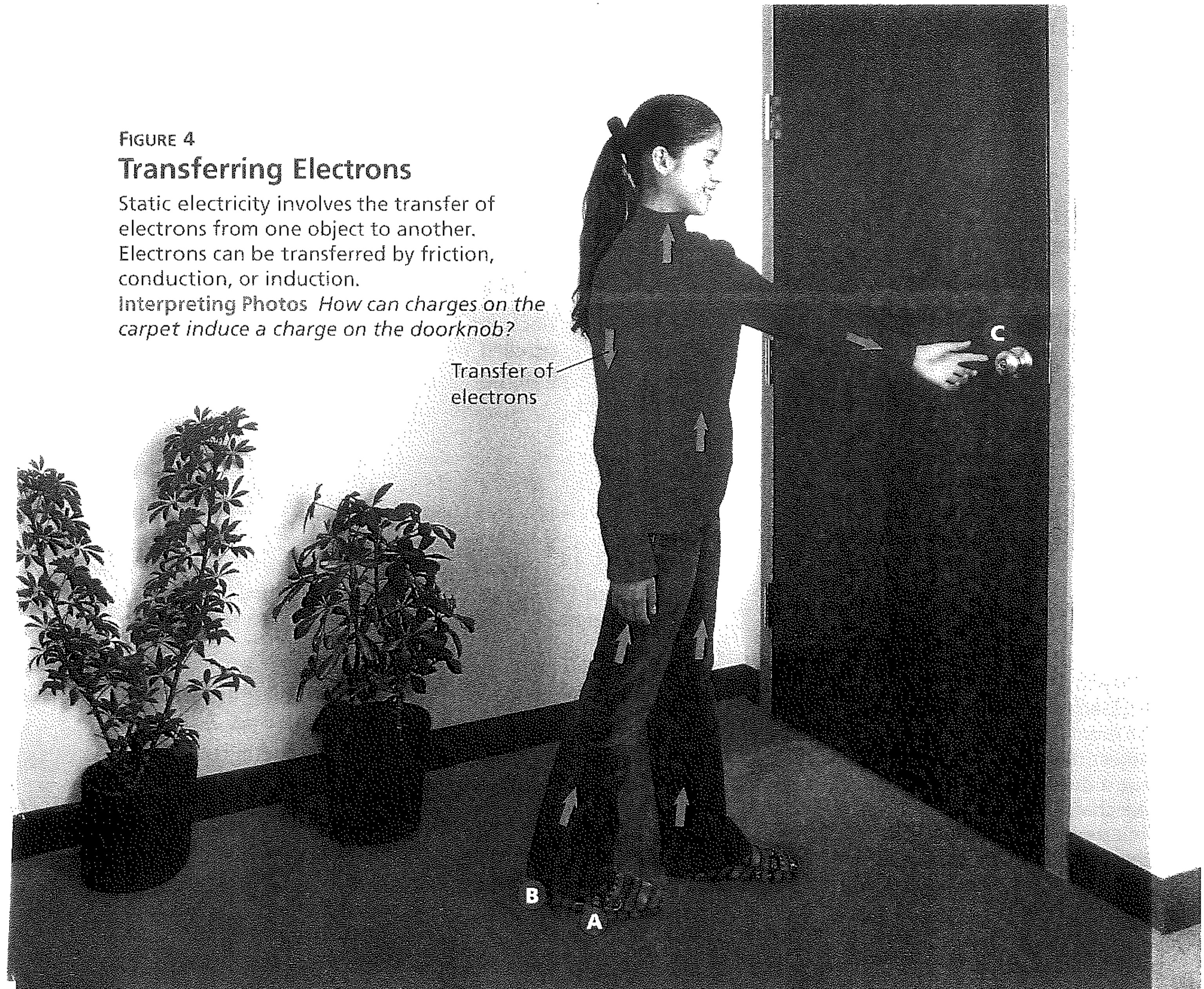


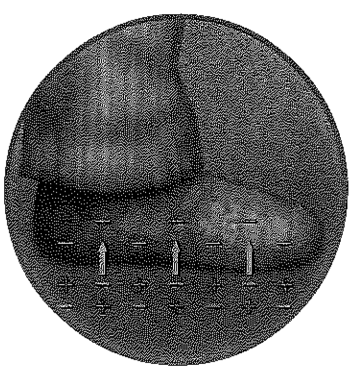
2. Rub a second foam plate on your hair. Place it upside down on a table.
3. Use the handle to pick up the pie plate. Hold the pie plate about 30 cm over the foam plate and drop it.
4. Now, very slowly, touch the tip of your finger to the pie plate. Be careful not to touch the foam plate. Then take your finger away.
5. Use the handle to pick up the pie plate again. Slowly touch the pie plate again.

Inferring What did you observe each time you touched the pie plate? How can you explain your observations?

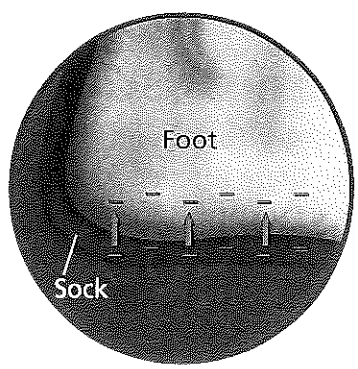
FIGURE 4
Transferring Electrons

Static electricity involves the transfer of electrons from one object to another. Electrons can be transferred by friction, conduction, or induction.
Interpreting Photos *How can charges on the carpet induce a charge on the doorknob?*

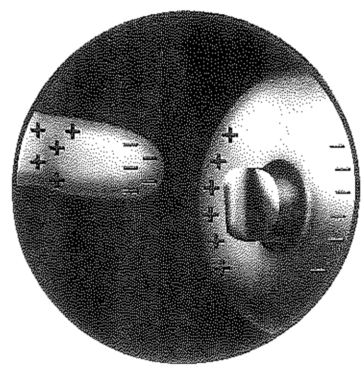




A Charging by Friction
Electrons are rubbed from the carpet to the girl's sock. The charges are distributed evenly over the sock.



B Charging by Conduction
When the negatively charged sock touches the skin, electrons are transferred by direct contact. Electrons are then distributed throughout the girl's body.



C Charging by Induction
Electrons on the girl's fingertip produce an electric field that repels negative charges and attracts positive charges on the doorknob. An overall positive charge is induced on the edge of the doorknob.

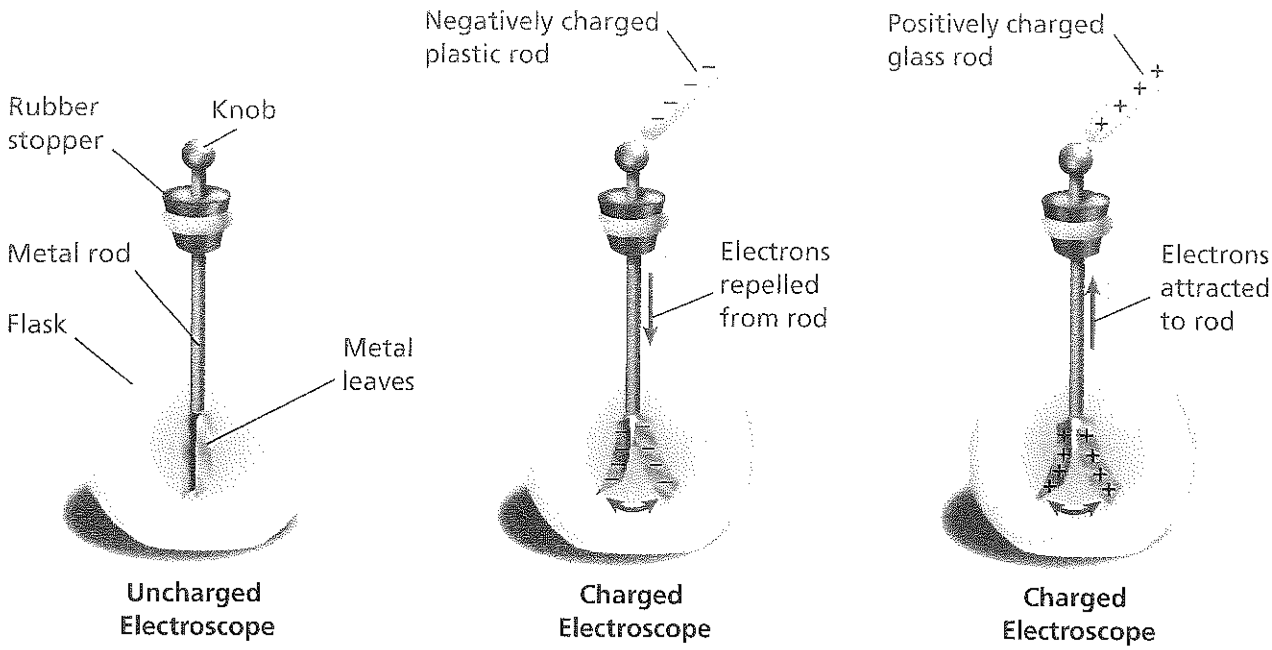


FIGURE 5
An Electroscope
An electroscope can be used to detect the presence of a charge, but it does not tell you whether the charge is positive or negative.
Relating Cause and Effect *Why do the leaves of the electroscope move apart when a charged object touches the knob?*

Detecting Charge Electric charge is invisible, but it can be detected by an instrument called an electroscope. A typical electroscope, shown in Figure 5, consists of a metal rod with a knob at the top and two thin metal leaves at the bottom. When the electroscope is uncharged, its metal leaves hang straight down. When a charged object touches the knob, electric charge travels by conduction into or out of the leaves. Since the charge on both leaves is the same, the leaves repel each other and spread apart. The leaves move apart in response to either negative charge or positive charge. Therefore, you cannot use an electroscope to determine the type of charge.

Static Discharge

Charges that build up as static electricity on an object don't stay there forever. Electrons tend to move, returning the object to its neutral condition. Consider what happens when two objects with opposite charges touch one another. **When a negatively charged object and a positively charged object are brought together, electrons transfer until both objects have the same charge.** The loss of static electricity as electric charges transfer from one object to another is called **static discharge.**

Often, a static discharge produces a spark. As electrons transfer between objects, they heat the air around the path they travel until it glows. The glowing air is the spark you see. The tiny spark you may have seen when you touch a doorknob or metal object is an example of static discharge.

Lightning is a dramatic example of static discharge. You can think of lightning as a huge spark. During thunderstorms, air swirls violently. Water droplets within the clouds become electrically charged. To restore a neutral condition in the clouds, electrons move from areas of negative charge to areas of positive charge and produce an intense spark. You see that spark as lightning.

Some lightning reaches Earth because negative charges at the bottom of storm clouds may cause the surface of Earth to become positively charged by induction. Electrons jump between the cloud and Earth's surface, producing a giant spark as they travel through the air. This is possible because of charging by conduction.

Reading Checkpoint **How is lightning formed?**

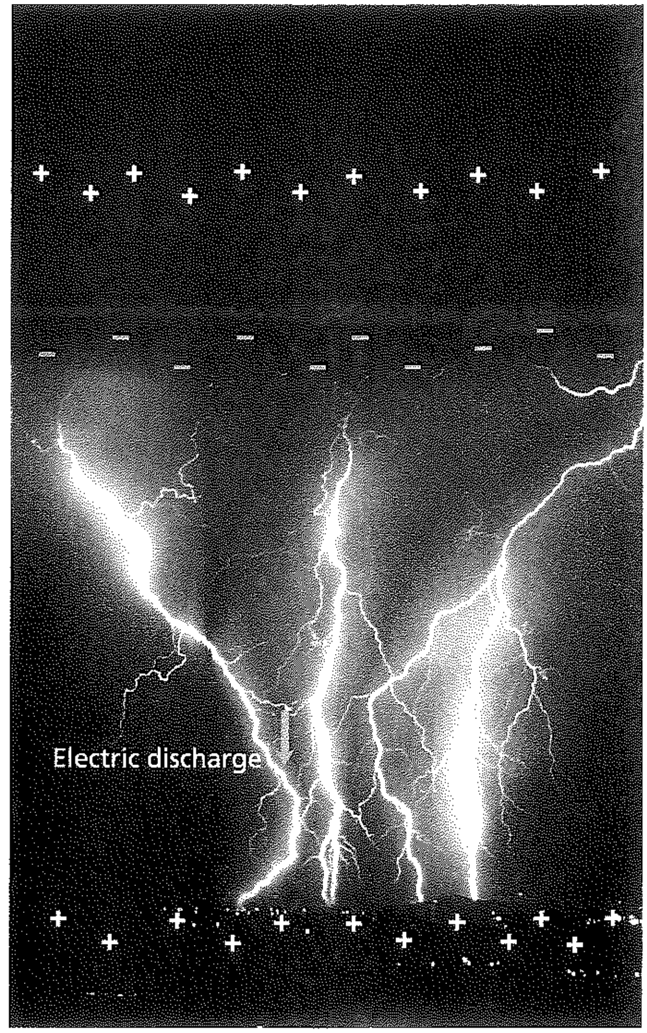


FIGURE 6
Static Discharge
Lightning is a spectacular discharge of static electricity. Lightning can occur within a cloud, between two clouds, or between a cloud and Earth.

Section 1 Assessment

Target Reading Skill Previewing Visuals Refer to your questions and answers about Figure 4 to help you answer Question 3 below.

Reviewing Key Concepts

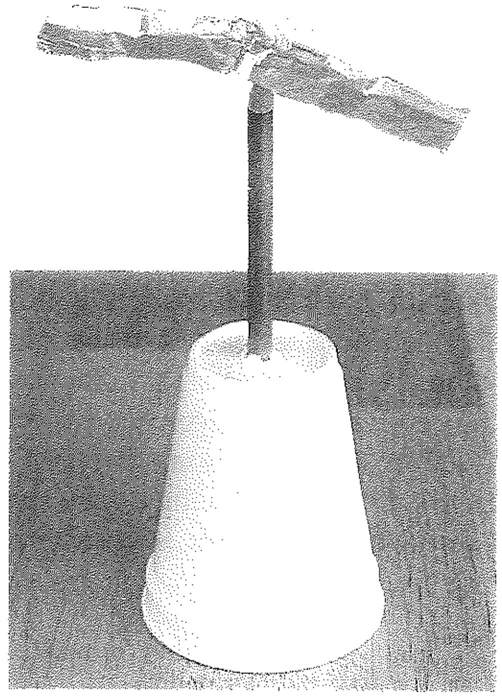
1. a. Identifying What are the two types of electric charge?
   b. Explaining How do objects with the same charge interact? How do objects with opposite charges interact?
   c. Comparing and Contrasting How are electric charges similar to magnetic poles? How are they different?
2. a. Defining What is an electric field?
   b. Interpreting Diagrams What do the lines represent in an electric field diagram?
3. a. Reviewing What is static electricity?
   b. Describing How is static electricity transferred during charging by conduction?
   c. Applying Concepts What role does induction play when lightning strikes Earth?

Lab zone At-Home Activity

TV Attraction Rub a balloon against your hair and bring the balloon near one of your arms. Observe the hair on your arm; then put down the balloon. Then bring your other arm near the front of a television screen that is turned on. Ask a family member to explain why the hairs on your arms are attracted to the balloon and to the screen. Explain that this is evidence that there is static electricity present on both the balloon and the screen.

Lab zone **Skills Lab**

The Versorium



Problem

A versorium is a device that was first described in 1600 by Sir William Gilbert. Why does a versorium turn?

Skills Focus

observing, predicting, classifying

Materials

- foam cup
- plastic foam plate
- pencil
- aluminum foil
- wool fabric
- paper
- scissors

Procedure

PART 1 Aluminum Foil Versorium

1. Cut a piece of aluminum foil approximately 3 cm by 10 cm.
2. Make a tent out of the foil strip by gently folding it in half in both directions.
3. Push a pencil up through the bottom of an inverted cup. **CAUTION:** *Avoid pushing the sharpened pencil against your skin.* Balance the center point of the foil tent on the point of the pencil as shown.
4. Make a copy of the data table.
5. Predict what will happen if you bring a foam plate near the foil tent. Record your prediction in the data table.
6. Predict what will happen if you rub the foam plate with wool fabric and then bring the plate near the foil tent. Record your prediction.
7. Predict what will happen if you bring the rubbed wool near the foil tent. Again record your prediction.
8. Test each of your three predictions and record your observations in the data table.

PART 2 Paper Tent Versorium

9. What might happen if you used a paper tent versorium instead of aluminum foil? Record your prediction for each of the three tests.
10. Test your prediction and record your observations in the data table.

Data Table

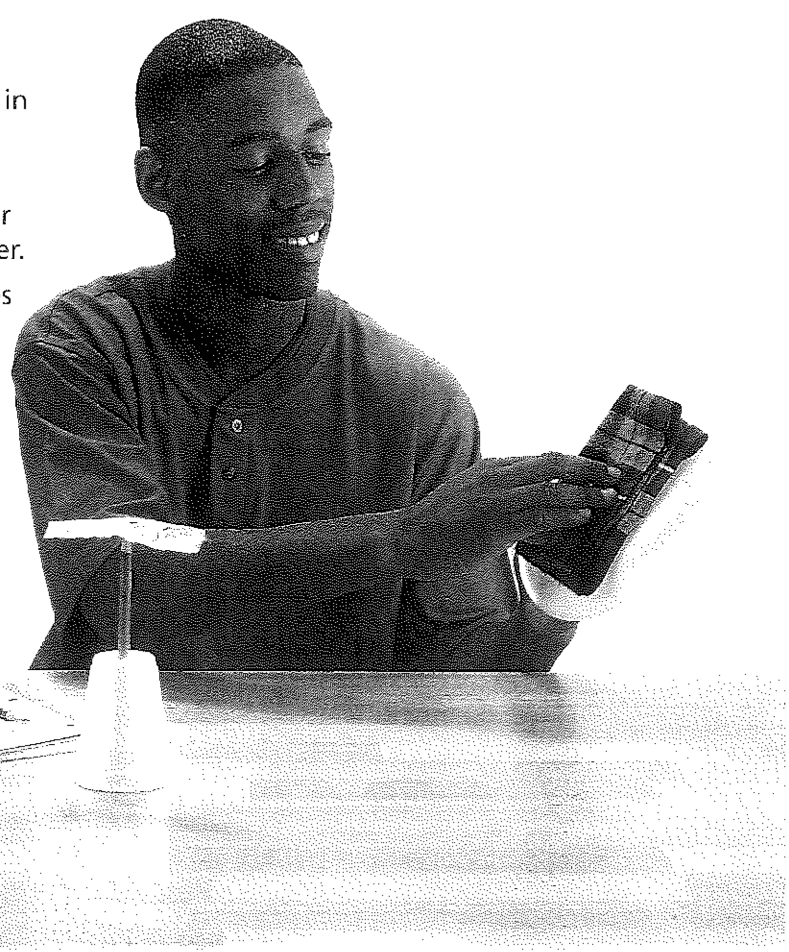
	Unrubbed Foam Plate	Rubbed Foam Plate	Rubbed Wool Fabric
Aluminum Tent: Prediction			
Aluminum Tent: Observation			
Paper Tent: Prediction			
Paper Tent: Observation			

Analyze and Conclude

1. Inferring At the beginning of the lab, is the foil negatively charged, positively charged, or uncharged? Use your observations to explain your answer.
2. Predicting Refer to the predictions you recorded in Steps 5, 6, and 7. Explain the reasoning behind those predictions.
3. Observing Did the behavior of the foil match each of your predictions in Steps 5, 6, and 7? Refer to your observations to explain your answer.
4. Classifying Did the effect of the foam plate differ in Steps 5 and 6? If so, identify which process—charging by friction, by conduction, or by induction—produced that change.
5. Classifying In Step 7, which process—charging by friction, by conduction, or by induction—explains the behavior of the foil when you brought the rubbed wool near it? Explain.
6. Predicting Explain the reasoning for your prediction about the paper tent versorium in Part 2.
7. Observing Did the behavior of the paper tent match your prediction in Step 9? Refer to your observations to explain your answer.
8. Drawing Conclusions Were the procedures and results in Part 2 generally similar to those in Part 1? Explain your answer with reference to charging by friction, by conduction, or by induction.
9. Controlling Variables During this lab, why is it important to avoid touching the foam plate or the wool with other objects before testing them with the versorium?
10. Communicating Another student who did this lab says that the versorium can show whether an object has a positive or negative charge. Write an e-mail to that student giving your reasons for agreeing or disagreeing.

Design an Experiment

What other materials besides foam or wool might have an effect on the versorium? What other materials could you use to make the versorium tent? Design an experiment to test specific materials and see how they respond. *Obtain your teacher's permission before carrying out your investigation.*



Section 2

Electric Current

Reading Preview

Key Concepts

- How is an electric current produced?
- How are conductors different from insulators?
- What causes electric charges to flow in a circuit?
- How does resistance affect current?

Key Terms

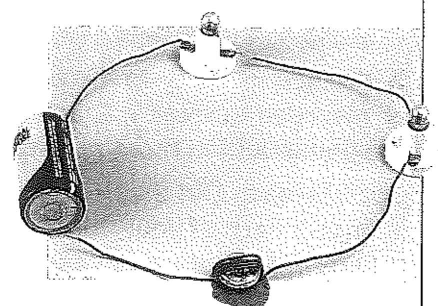
- electric current
- electric circuit
- conductor
- insulator
- voltage
- voltage source
- resistance

Target Reading Skill

Outlining As you read, make an outline about electric current. Use the red headings for the main ideas and the blue headings for the supporting ideas.

Lab zone Discover Activity

How Can Current Be Measured?

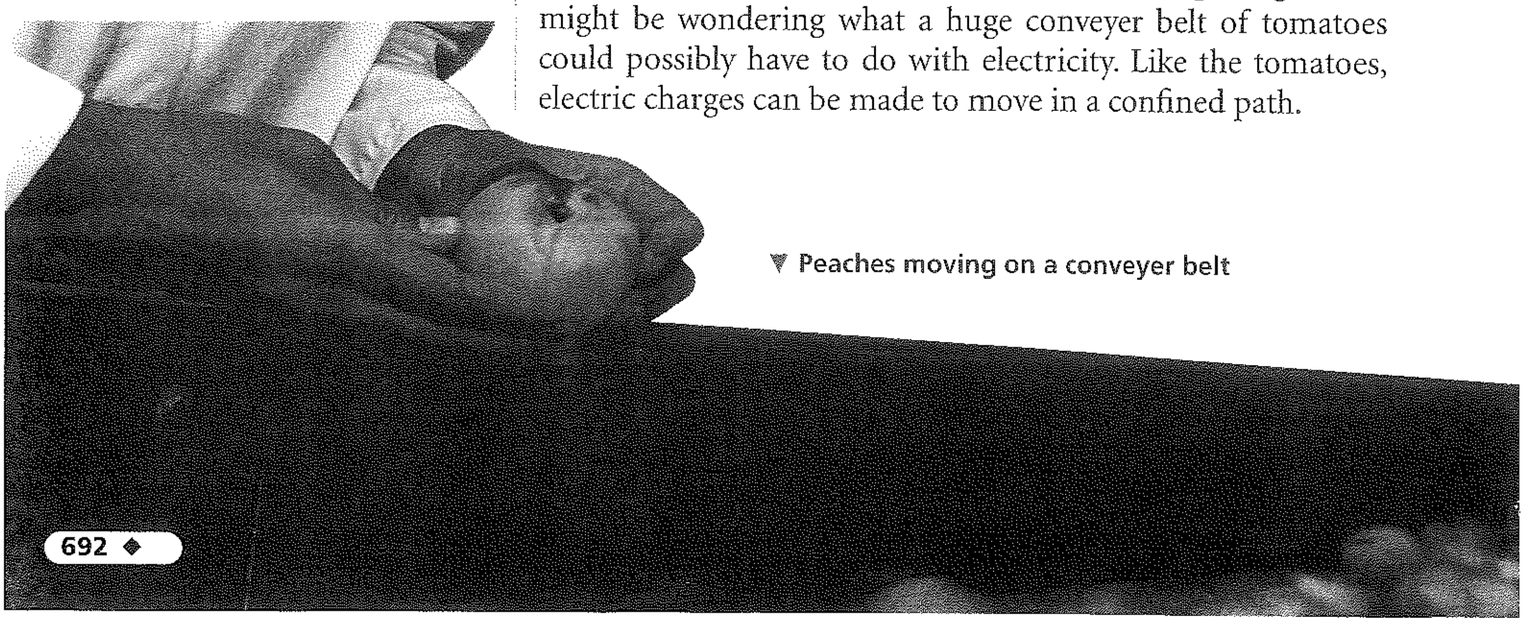


1. Obtain four pieces of wire with the insulation removed from both ends. Each piece should be about 25 cm long.
2. Wrap one of the wires four times around a compass as shown. You may use tape to keep the wire in place.
3. Build a circuit using the remaining wire, wrapped compass, two bulbs, and a D-cell as shown. Adjust the compass position so that the wire is aligned directly over the compass needle.
4. Make sure the compass is level. If it is not, place it on a piece of modeling clay so that the needle swings freely.
5. Observe the compass needle as you complete the circuit. Record the number of degrees the needle moves.
6. Repeat the activity using only one bulb, and again with no bulb. Record the number of degrees the needle moves.

Think It Over

Inferring Based on your observations of the compass, when did the compass needle move the most? How can you explain your observations?

Thousands of tomatoes ride along a conveyer belt through a giant machine. The conveyer belt carries the tomatoes through a cleaning station, a sorter, and into a lane to be packaged. You might be wondering what a huge conveyer belt of tomatoes could possibly have to do with electricity. Like the tomatoes, electric charges can be made to move in a confined path.



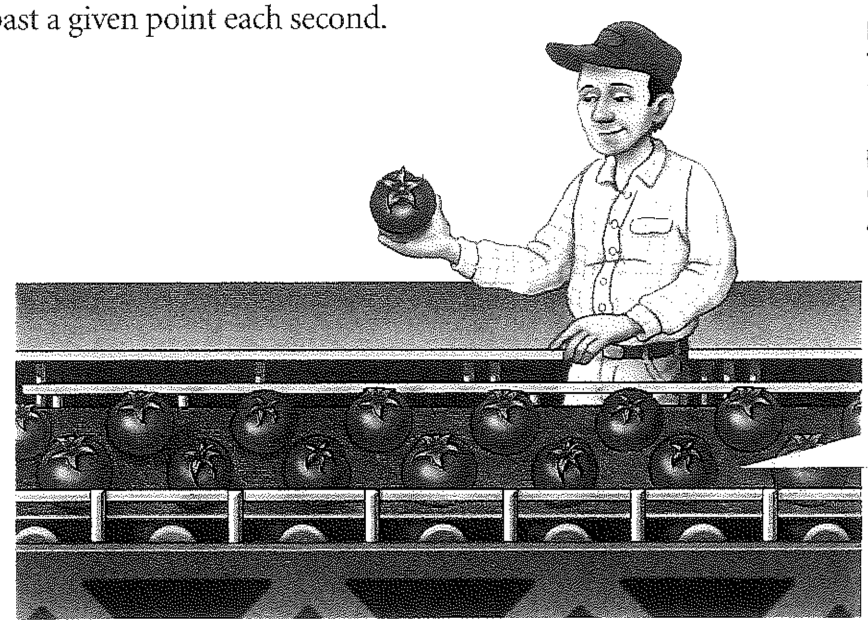
▼ Peaches moving on a conveyer belt

Flow of Electric Charges

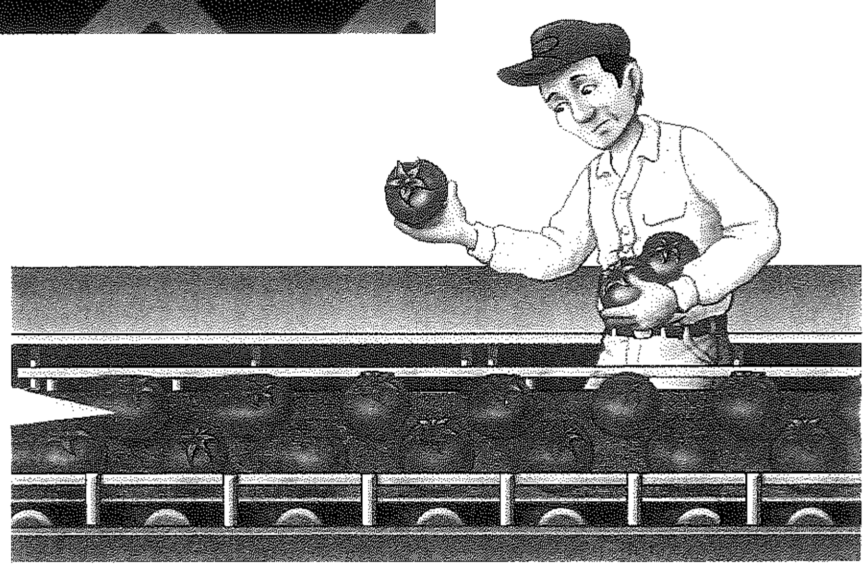
Lightning releases a large amount of electrical energy. However, the electric charge from lightning can't be used to power your TV, clock radio, video game, or kitchen lights because it only lasts for an instant. These electric devices need electric charges that flow continuously. They require electric current.

What Is Electric Current? Recall that static electric charges do not flow continuously. However, when electric charges are made to flow through a wire or similar material, they produce an electric current. **Electric current** is the continuous flow of electric charges through a material. The amount of charge that passes through the wire in a unit of time is the rate of electric current. The unit for the rate of current is the ampere, named for André Marie Ampère, an early investigator of electricity. The name of the unit is often shortened to *amp* or *A*. The number of amps describes the amount of charge flowing past a given point each second.

FIGURE 7
Representing an Electric Current
Tomatoes moving on a conveyer belt are similar to charges moving in a wire, or electric current.
Interpreting Photos *Which characteristics of electric current are represented in the illustrations?*



Tomatoes on a conveyer belt are similar to electric current in a wire. Both the tomatoes and the current move in a confined path.



If the tomatoes move faster, more tomatoes pass the worker every second. Similarly, if current is increased in a wire, more charges pass by a point on the wire every second.

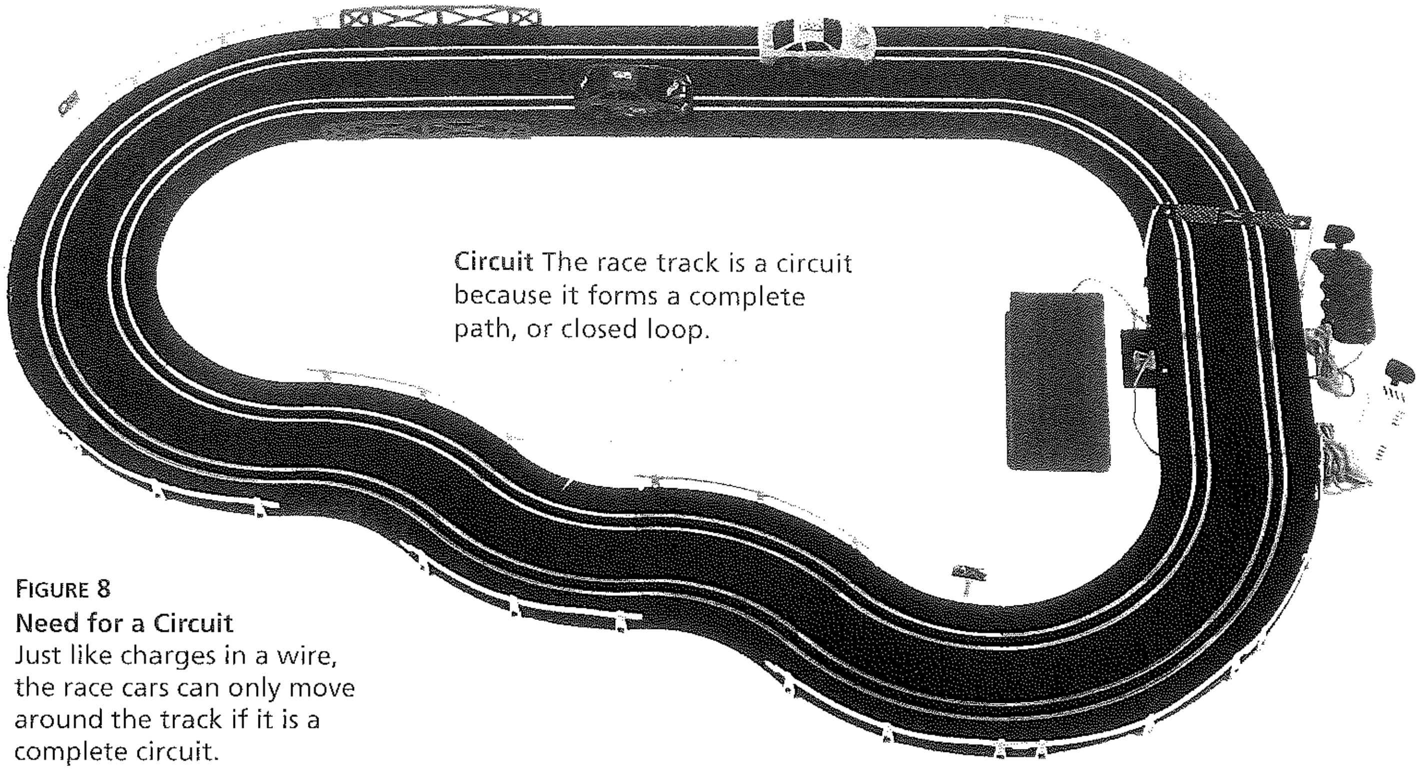


FIGURE 8
Need for a Circuit
Just like charges in a wire, the race cars can only move around the track if it is a complete circuit.

Current in a Circuit Electric current does not automatically exist in a material. Current requires a specific path to follow. **To produce electric current, charges must flow continuously from one place to another.** Current requires an electric circuit. An **electric circuit** is a complete, unbroken path through which electric charges can flow.

The cars on the racetrack in Figure 8 are like the charges in an electric circuit. If the racetrack forms a complete loop, the cars can move around the track continuously. However, if a piece of the racetrack is missing, the cars are unable to move around the loop. Similarly, if an electric circuit is complete, charges can flow continuously. If an electric circuit is broken, charges will not flow.

Electric circuits are all around you. All electrical devices, from toasters to radios to electric guitars and televisions, contain electric circuits. You will learn more about the characteristics of electric circuits in Section 4.

Reading Checkpoint **What is an electric circuit?**

Conductors and Insulators

Charges flow easily through a circuit made of metal wires. But would charges flow in wires made of plastic? The answer is no. Electric charges do not flow easily through every material. **A conductor transfers electric charge well. An insulator does not transfer electric charge well.** Figure 9 shows materials that are good conductors and materials that are insulators.

Conductors Metals, such as silver, copper, aluminum, and iron, are good conductors. A **conductor** is a material through which charge can flow easily. In a conductor, atoms contain electrons that are bound loosely. These electrons, called conduction electrons, are able to move throughout the conductor. As these electrons flow through a conductor, they form an electric current. Conductors are used to carry electric charge.

Did you ever wonder why a light goes on the instant you flip the switch? How do the electrons get to your lamp from the electric company so fast? The answer is that electrons are not sent to your house when you flip a switch. They are already present inside the conductors that make up the circuit. When you flip the switch, electrons at one end of the wire are pulled, while those at the other end are pushed. The result is a continuous flow of electrons through all parts of the circuit as soon as the circuit is completed.

Insulators A material through which charges cannot flow easily is called an **insulator**. The electrons in an insulator are bound tightly to their atoms and do not move easily. Rubber, glass, sand, plastic, and wood are good insulators. Insulators are used to stop the flow of charges.

The rubber coating on an appliance cord is an example of an insulator. A cord carries charges from an electrical outlet to an appliance. So why don't you get a shock when you touch a cord? The inner wire is the conductor for the current. The rubber coating around the wire is an insulator. The cord allows charge to continue to flow to the appliance, but stops it from flowing into your hand and shocking you.

Reading Checkpoint **Why don't you get a shock from touching an extension cord?**

Go Online
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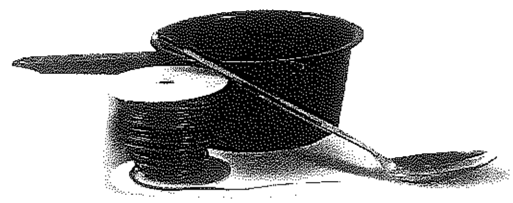
For: More on electric current
Visit: PHSchool.com
Web Code: cgd-4022

Conductors



Insulators

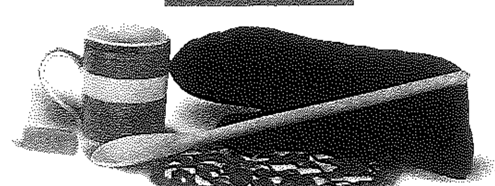


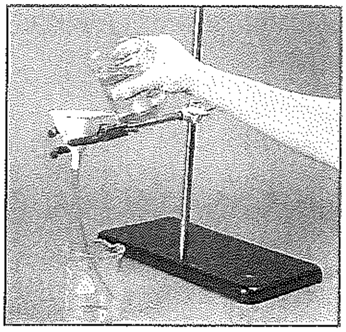
FIGURE 9
Conductors and Insulators
Charges easily move through conductors. In contrast, charges do not move easily through insulators. Classifying *In which category do metals belong?*

Lab zone **Try This Activity**

Down the Tubes

Use water to model voltage.

1. Set up a funnel, tubing, beaker, and ring stand as shown.



2. Have a partner start a stopwatch as you pour 200 mL of water into the funnel.
3. Stop the stopwatch when all of the water has flowed into the beaker.
4. Repeat steps 2 and 3 setting the funnel at different heights.

Making Models How did your model represent voltage? How did changing the height affect the model's "voltage"?

Voltage

Imagine you are on a roller coaster at an amusement park. Strapped in your seat, you wait anxiously as your car climbs to the top of the hill. Then, whoosh! Your car speeds down the steel track. Believe it or not, electric charges flow in much the same way as your roller coaster car moves on the track.

Charges Need Energy to Flow The roller coaster cars need energy to give you an exciting ride, but they have no energy when you first climb aboard. A motor provides energy to move a chain attached to the cars. The moving chain pulls the cars to the top of the hill. As they climb, the cars gain potential energy. Potential energy is the energy an object has as a result of its position, or height. The higher up the hill the chain carries the cars, the more potential energy the cars gain. Then, after reaching the hilltop, the cars rush down the hill. As they do, they move from a place of high potential energy—the hilltop—to a place of low potential energy—the bottom of the hill. It is the difference in potential energy between the hilltop and the bottom of the hill that allows the cars to speed down the hill.

In a similar way, charges in an electric circuit flow because of a difference in electrical potential energy. Think of the charges that make up the electric current as being like the roller coaster cars. The circuit is like the steel track. An energy source, such as a battery, is like the roller coaster motor. The battery provides the potential energy difference for the circuit. However, its potential energy is not related to height, as in the roller coaster. Instead it is related to the charges inside the battery.

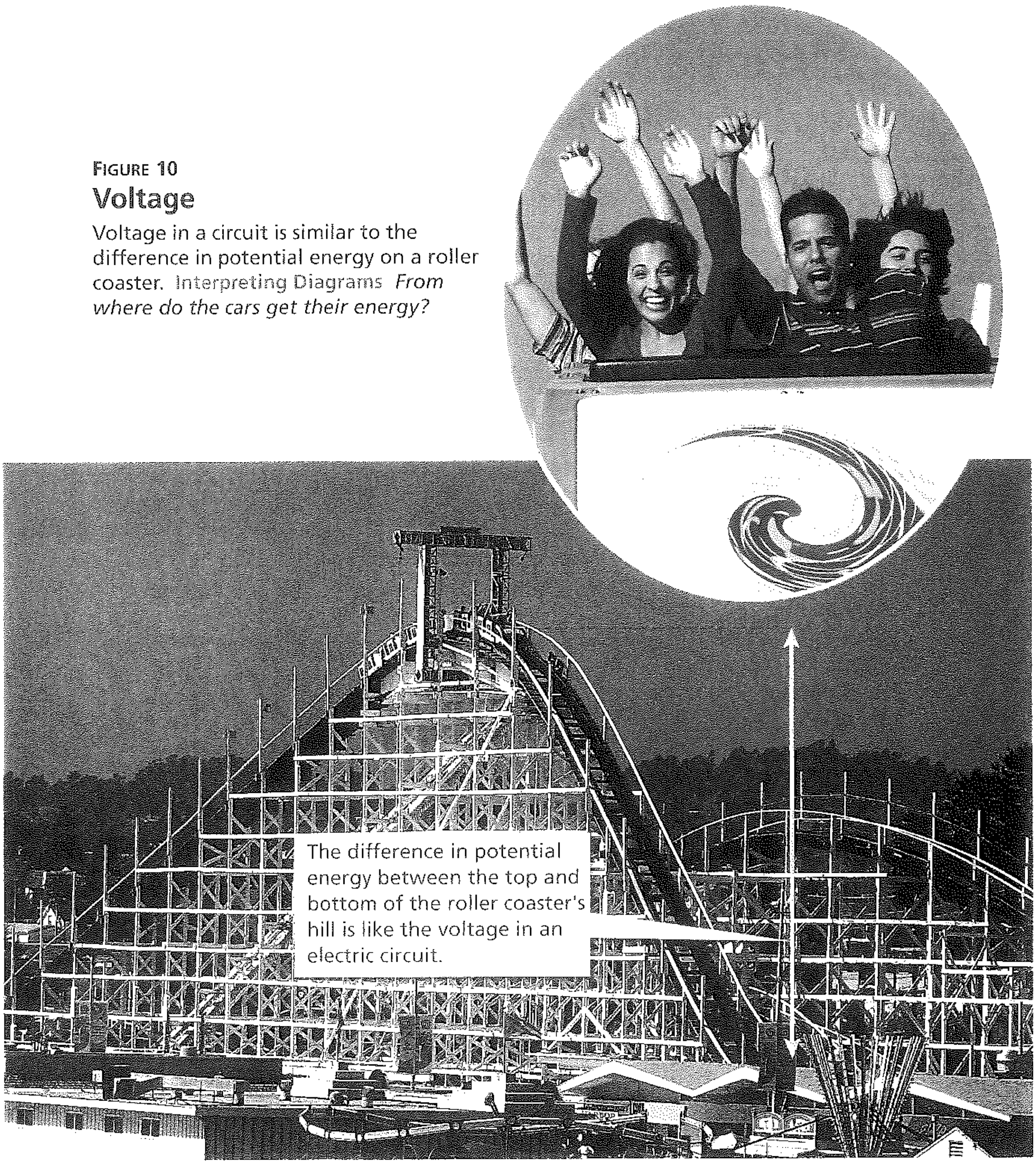
Voltage Just as the roller coaster creates a difference in potential energy between two places, so does an electric circuit. The difference in electrical potential energy between two places in a circuit is called **voltage,** or potential difference. The unit of measure of voltage is the volt (V). **Voltage causes a current in an electric circuit.** You can think of voltage as the amount of force pushing an electric current.

Voltage Sources At the amusement park, if there were no way of pulling the roller coaster cars to the top of the first hill, there would be no ride. Recall that the ride has a source of energy, a motor. The motor moves the chain that takes the cars to the top of the hill. Once the cars reach the top of any hill, they gain a high potential energy.

An electric circuit also requires a source of energy, such as a battery, to maintain a voltage. A **voltage source** is a device that creates a potential difference in an electric circuit. Batteries and generators are examples of voltage sources. A voltage source has two terminals. The voltage between the terminals causes charges to move around the circuit.

Reading Checkpoint **What does a voltage source do?**

FIGURE 10
Voltage
Voltage in a circuit is similar to the difference in potential energy on a roller coaster. Interpreting Diagrams *From where do the cars get their energy?*



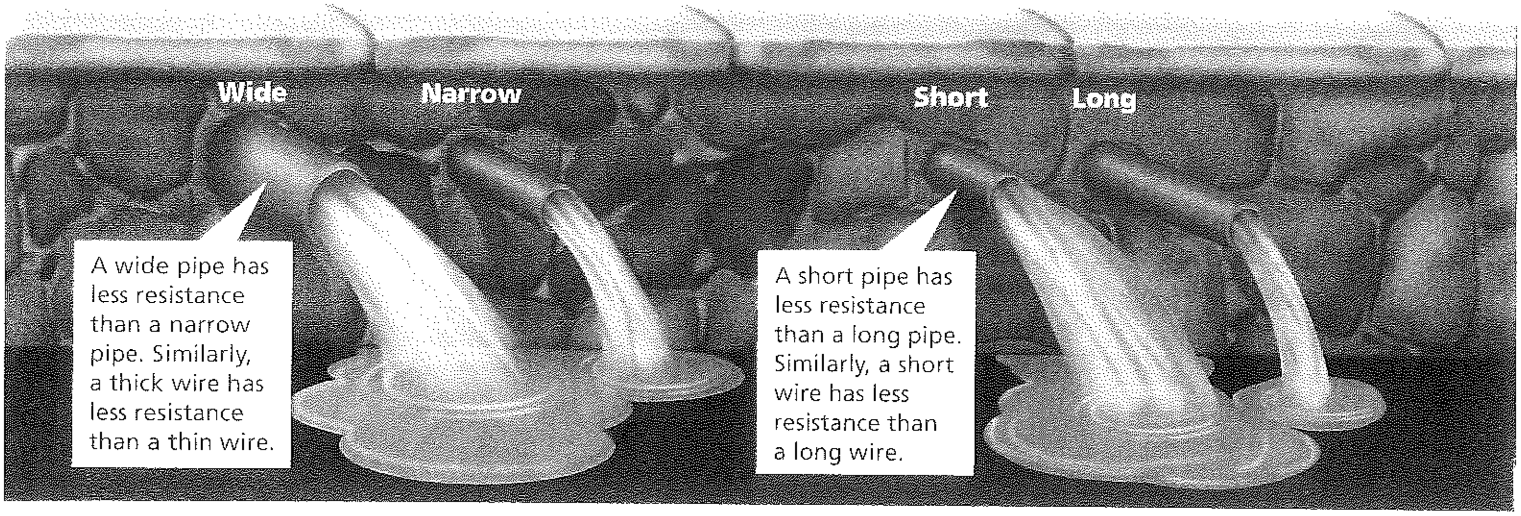


FIGURE 11
Resistance
Two factors that affect the resistance of water flowing in a pipe are diameter and length. The diameter and length of a wire also affect resistance in a circuit.
Inferring *If you reduce the resistance in a circuit, will there be more or less current?*

Resistance

In the example of the roller coaster, you only learned how the height difference, or "voltage," affected the cars' speed. But other factors affect how fast the cars move. For instance, if the roller coaster cars have rusty wheels, their speed will decrease because the wheels do not turn as well. Current in a circuit works in a similar way.

Current Depends on Resistance The amount of current that exists in a circuit depends on more than just the voltage. Current also depends on the resistance of the material. **Resistance** is the measure of how difficult it is for charges to flow through a material. **The greater the resistance, the less current there is for a given voltage.** The unit of measure of resistance is the ohm (Ω). The ohm is named for Georg Ohm, a German physicist who investigated resistance.

Factors That Determine Resistance There are four factors that determine the resistance of a wire, or any object. The first factor is the material from which the wire is made. Some materials, such as insulators, have electrons that are tightly held to their atoms. Insulators have a high resistance because it is difficult for charges to move. Other materials, such as conductors, have electrons that are loosely held to their atoms. Conductors have a low resistance because charges can move through them easily.

The second factor is length. Long wires have more resistance than short wires. The resistance of current in a wire can be compared to the resistance of water flowing through a pipe. Suppose water is being released from a reservoir held by a dam. As shown in Figure 11, less water flows from the reservoir through the long pipe than through the short pipe. The water in the long pipe slows down because it bumps into more of the pipe's inner wall.

Diameter is the third factor. In Figure 11, the pipe with the small diameter has less water flowing through it than the pipe with the large diameter. In the small-diameter pipe, there is less area through which the water can flow. Similarly, thin wires have more resistance than thick wires.

The fourth factor that determines the resistance of a wire is the temperature of the wire. The electrical resistance of most materials increases as temperature increases. As the temperature of most materials decreases, resistance decreases as well.

Figure 12
Which Path?
Charges flow through the wire, not the bird, because the wire offers less resistance.

Path of Least Resistance Perhaps you have heard it said that someone is taking the "path of least resistance." This means that the person is doing something in the easiest way possible. In a similar way, if electric charge can flow through either of two paths, more of the charge will flow through the path with lower resistance.

Have you seen a bird perched on an uninsulated electric fence? The bird doesn't get hurt because charges flow through the path of least resistance. Since the bird's body offers more resistance than the wire, charges flow directly through the wire without harming the bird.

Reading Checkpoint **What is the "path of least resistance"?**

Section 2 Assessment

Target Reading Skill Outlining Use your outline to help you answer the questions below.

Reviewing Key Concepts

1. a. Reviewing What happens when an electric current is produced?
   b. Comparing and Contrasting Contrast electric current and static electricity.
   c. Relating Cause and Effect Explain why electric current cannot exist if an electric circuit is broken.
2. a. Defining Define *conductor* and *insulator.*
   b. Listing List materials that make good conductors. List materials that are insulators.
   c. Applying Concepts If a copper wire in a working electric circuit is replaced by a piece of rubber tubing, will there be a current in the circuit? Explain.
3. a. Listing What are two examples of voltage sources?
   b. Explaining How does voltage cause electrons to flow in a circuit?
   c. Predicting The electrical potential energy at one point in a circuit is greater than the electrical potential energy at another point. Will there be a current between the two points? Explain.
4. a. Reviewing What is resistance?
   b. Summarizing What are four factors that determine resistance?

Writing in Science

Analogies An analogy can help people understand new information by comparing it to something familiar. Write a paragraph that compares an electric circuit to skiing down a slope and riding the chairlift to the top.

Lab zone **Skills Lab**

Constructing a Dimmer Switch

Problem

What materials can be used to make a dimmer switch?

Skills Focus

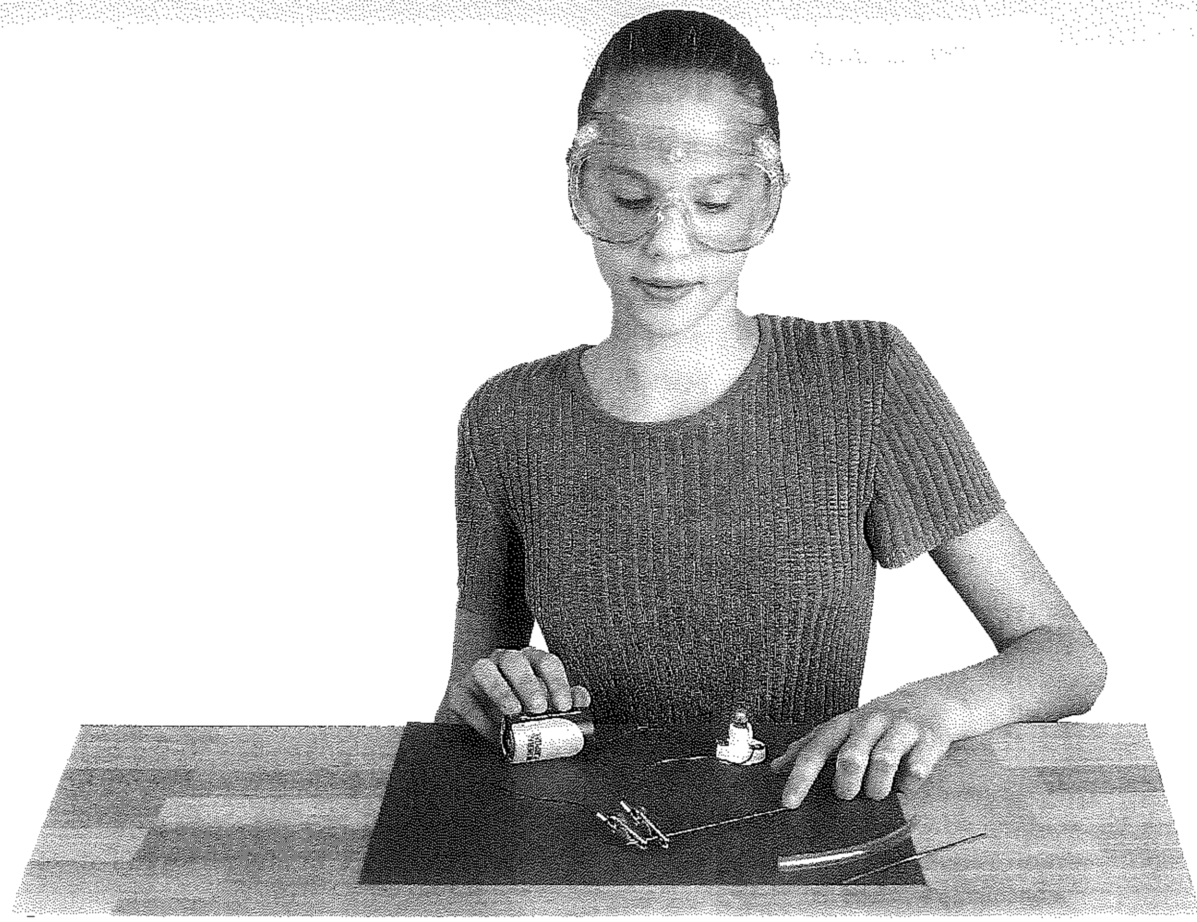
predicting, observing

Materials

- D-cell
- masking tape
- flashlight bulb in a socket
- thick lead from mechanical pencil
- uninsulated copper wire, the same length as the pencil lead
- rubber tubing, the same length as the pencil lead
- 1 wire, 10–15 cm long
- 2 wires, 20–30 cm long
- 2 alligator clips

Procedure

1. To make a device that can dim a light bulb, construct the circuit shown in the photo on the opposite page. To begin, attach wires to the ends of the D-cell.
2. Connect the other end of one of the wires to the bulb in a socket. Attach a wire with an alligator clip to the other side of the socket.
3. Attach an alligator clip to the other wire.
4. The pencil lead will serve as a resistor that can be varied—a variable resistor. Attach one alligator clip firmly to the tip of the pencil lead. Be sure the clip makes good contact with the lead. (*Note*: Pencil "lead" is actually graphite, a form of the element carbon.)
5. Predict how the brightness of the bulb will change as you slide the other alligator clip back and forth along the lead. Test your prediction.



6. What will happen to the brightness of the bulb if you replace the lead with a piece of uninsulated copper wire? Adapt your pencil-lead investigation to test the copper wire.
7. Predict what will happen to the brightness of the bulb if you replace the pencil lead with a piece of rubber tubing. Adapt your pencil-lead investigation to test the rubber tubing.

Analyze and Conclude

1. Controlling Variables What variable did you manipulate by sliding the alligator clip along the pencil lead in Step 5?
2. Observing What happened to the brightness of the bulb when you slid the alligator clip along the pencil lead?
3. Predicting Explain your reasoning in making predictions about the brightness of the bulb in Steps 6 and 7. Were your predictions supported by your observations?
4. Interpreting Data Do you think that pencil lead has more or less resistance than copper? Do you think it has more or less resistance than rubber? Use your observations to explain your answers.
5. Drawing Conclusions Which material tested in this lab would make the best dimmer switch? Explain your answer.
6. Communicating Suppose you want to sell your dimmer switch to the owner of a theater. Write a product information sheet that describes your device and explains how it works.

More to Explore

The volume controls on some car radios and television sets contain resistors that can be varied, called rheostats. The sliding volume controls on a sound mixing board are rheostats as well. Homes and theaters may use rheostats to adjust lighting. Where else in your house would rheostats be useful? (*Hint*: Look for applications where you want to adjust a device gradually rather than just turn it on or off.)

Section 3 Integrating Chemistry

Batteries

Reading Preview

Key Concepts

- What was the first battery made of?
- How does an electrochemical cell work?

Key Terms

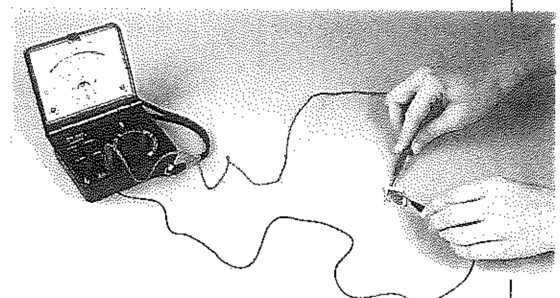
- chemical energy
- chemical reaction
- electrochemical cell
- electrode
- electrolyte
- terminal
- battery
- wet cell
- dry cell

Target Reading Skill

Building Vocabulary After you read the section, reread the paragraphs that contain definitions of Key Terms. Use the information you have learned to write a definition of each Key Term in your own words.

Lab zone Discover Activity

Can You Make Electricity Using a Penny?



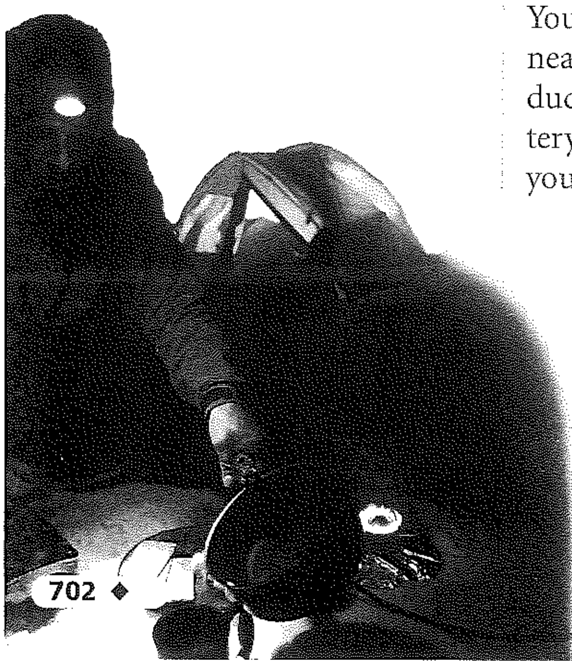
1. Clean a penny with vinegar. Wash your hands.
2. Cut a 2-cm × 2-cm square from a paper towel and a similar square from aluminum foil.
3. Stir salt into a glass of warm water until the salt begins to sink to the bottom. Then soak the paper square in the salt water.
4. Put the penny on your desktop. Place the wet paper square on top of it. Then place the piece of aluminum foil on top of the paper.
5. Set a voltmeter to read DC volts. Touch the red lead to the penny and the black lead to the foil. Observe the reading on the voltmeter.

Think It Over

Observing What happened to the voltmeter? What type of device did you construct?

When you finally step into camp, barely enough light is left to see the trees in front of you. But you must still set up your tent. You need more light. There are no generators or electric lines nearby. Where can you find enough electrical energy to produce some light? Fortunately, your headlamp contains a battery that provides electrical energy to its bulb. In this section, you'll find out how a battery produces electrical energy.

Using a headlamp for light ▼



The First Battery

Energy can be transformed from one form into another. For example, batteries transform chemical energy into electrical energy. **Chemical energy** is energy stored in chemical compounds.

Luigi Galvani The research that led to the development of the battery came about by accident. In the 1780s, an Italian physician named Luigi Galvani was studying the anatomy, or body structure, of a frog. He was using a brass hook to hold a leg muscle in place. As he touched one end of the hook to an iron railing, he noticed that the frog's leg twitched. Galvani hypothesized that there was some kind of "animal electricity" present only in living tissue. This hypothesis was later proven to be incorrect. However, Galvani's observations and hypothesis led to further research.

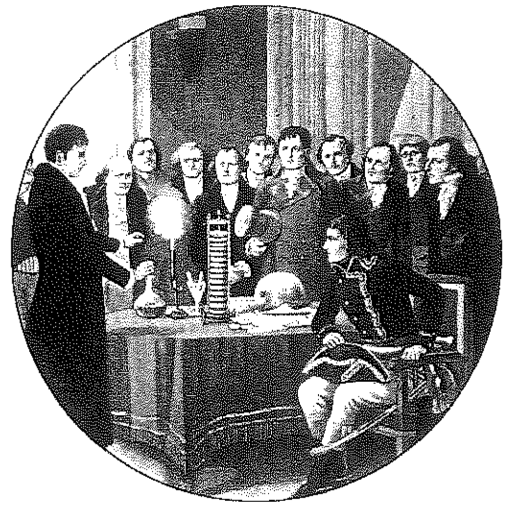
Alessandro Volta An Italian scientist named Alessandro Volta developed a different hypothesis to account for Galvani's observations. Volta argued that the electrical effect Galvani observed was actually a result of a chemical reaction. A **chemical reaction** is a process in which substances change into new substances with different properties. In this case, Volta hypothesized that a chemical reaction occurred between the two different metals (the iron railing and the brass hook) and the salty fluids in the frog's leg muscle.

To confirm his hypothesis, Volta placed a piece of paper that had been soaked in salt water in between a piece of zinc and a piece of silver. Volta found that if he connected wires to the silver and zinc, current was produced. Then he repeated the layers: zinc, paper, silver, zinc, and so on. When he added more layers, a greater current was produced. If you did the Discover activity, you did something similar to what Volta did.

Volta built the first electric battery by layering zinc, paper soaked in salt water, and silver. In 1800, he made his discovery public. Although his battery was much weaker than those made today, it produced a current for a relatively long period of time. Volta's battery was the basis of more powerful modern batteries.

Reading Checkpoint **What is a chemical reaction?**

FIGURE 13
The First Battery
Alessandro Volta demonstrates the first battery. Interpreting Diagrams *What materials made up Volta's battery?*



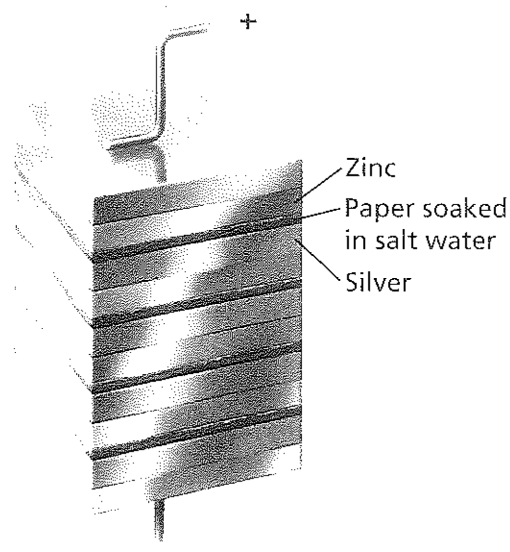
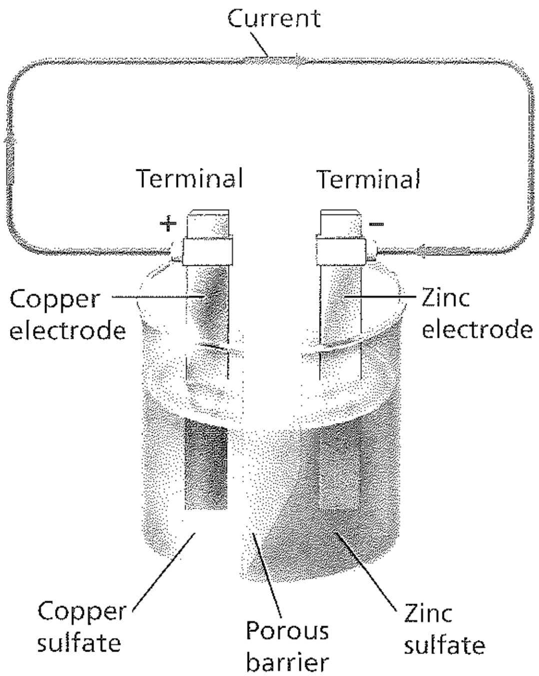


FIGURE 14
An Electrochemical Cell
An electrochemical cell can make a complete circuit. Sequencing *Start with the negative terminal and trace the path of the current from the terminal and back to it.*



Electrochemical Cells

In Volta's setup, each pair of zinc and silver layers separated by paper soaked in salt water acted as an electrochemical cell. An **electrochemical cell** is a device that transforms chemical energy into electrical energy. An electrochemical cell consists of two different metals called **electrodes**, which are immersed in a substance called an electrolyte. An **electrolyte** is a substance that conducts electric current. Volta used silver and zinc as electrodes and salt water as his electrolyte.

A Simple Cell In the cell in Figure 14, the electrolytes are copper sulfate and zinc sulfate separated by a barrier and mixed with water. The electrodes are made of copper and zinc. The part of an electrode above the surface of the electrolyte is called a **terminal**. The terminals are used to connect the cell to a circuit.

Chemical reactions occur between the electrolyte and the electrodes in an electrochemical cell. These reactions cause one electrode to become negatively charged and the other electrode to become positively charged. Because the electrodes have opposite charges, there is a voltage between them. Recall that voltage causes charges to flow. If the terminals are connected by a wire, charge will flow from one terminal to the other. In other words, the electrochemical cell produces an electric current in the wire. The barrier allows charges to flow through the electrolytes to make a complete circuit but prevents the copper and zinc from mixing.

Batteries Several electrochemical cells can be stacked together to form a battery. A **battery** is a combination of two or more electrochemical cells in a series. Today, single cells are often referred to as "batteries." So the "batteries" you use in your flashlight are technically cells rather than batteries.

In a battery, two or more electrochemical cells are connected in series. This means the positive terminal of one cell is connected to the negative terminal of the next. You connect two cells in this way inside a flashlight. The total voltage of a battery is found by adding the voltages of the individual cells.

Reading Checkpoint **What is a battery?**

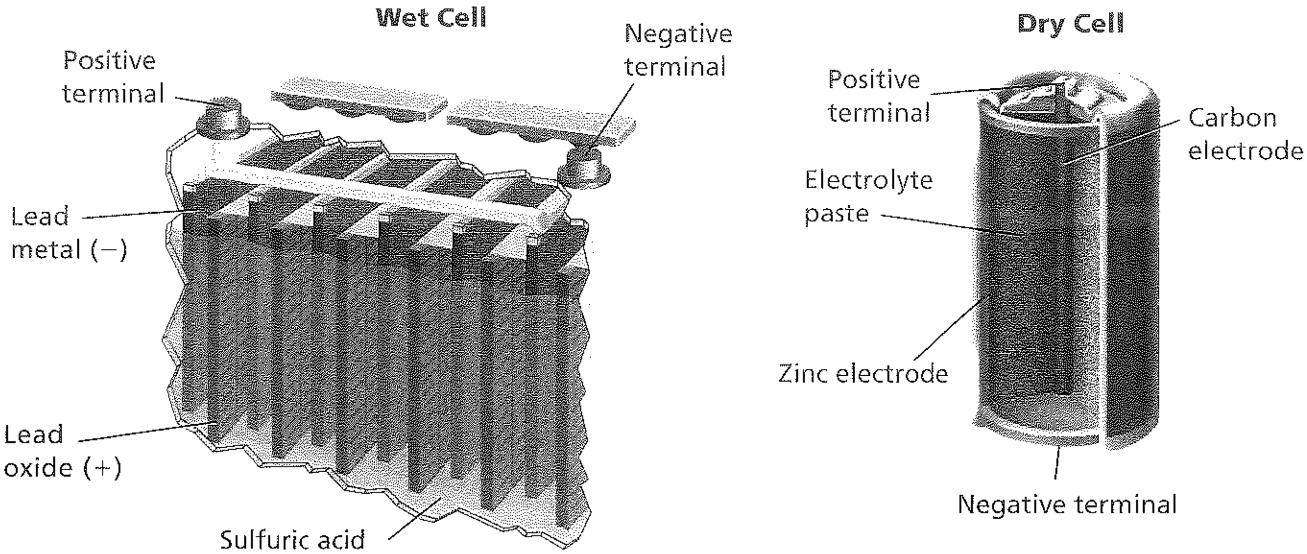


FIGURE 15
Wet and Dry Cells
The wet electrolyte in the car battery on the left is sulfuric acid. The diagram on the right shows the parts of a typical dry cell. The electrolyte is not really dry — it is a paste.

Wet Cells There are two kinds of electrochemical cells: wet cells and dry cells. An electrochemical cell in which the electrolyte is a liquid is a **wet cell**. Volta's battery consisted of wet cells because the electrolyte was salt water. The 12-volt automobile battery in Figure 15 consists of six wet cells. In this case, the electrolyte is sulfuric acid.

Dry Cells Flashlights and many other devices use dry cells. A **dry cell** is an electrochemical cell in which the electrolyte is a paste. Figure 15 shows the parts of a dry cell.

Section 3 Assessment

Target Reading Skill Building Vocabulary Use your definitions to help answer the questions.

Reviewing Key Concepts

1. a. Describing Describe the parts of Volta's battery and how they were arranged.
   b. Explaining What happened when Volta connected the parts of his cells in a circuit?
   c. Relating Cause and Effect What caused the event in Question b to happen?
   d. Explaining Explain how Volta used Galvani's observations to develop a relationship between chemical energy and electrical energy.
2. a. Listing What are the parts of an electrochemical cell?
   b. Summarizing Summarize how the parts of a cell interact to produce a current.
   c. Predicting Would a current be produced if both terminals had the same charge? Explain your answer.

Lab zone At-Home Activity

Reviving Old Cells Test a flashlight with two old D-cells and observe its brightness. Then ask a family member to remove the D-cells and place them in direct sunlight to warm up. After an hour or more, use the cells to test the flashlight. Compare the brightness of the bulb in the two tests. Explain what your observations indicate about the chemical reactions in the battery.

Section 4

Electric Circuits and Power

Reading Preview

Key Concepts

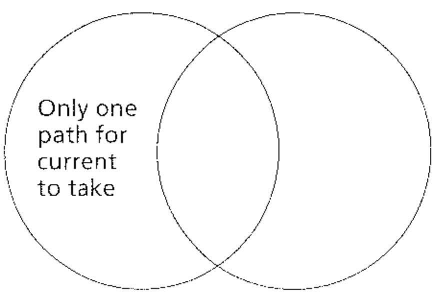
- What is Ohm's law?
- What are the basic features of an electric circuit?
- How many paths can currents take in series and parallel circuits?
- How do you calculate electric power and the energy used by an appliance?

Key Terms

- Ohm's law
- series circuit
- ammeter
- parallel circuit
- voltmeter
- power

Target Reading Skill

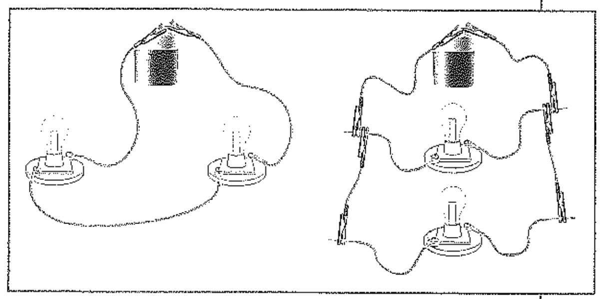
Comparing and Contrasting As you read, compare and contrast series circuits and parallel circuits in a Venn diagram like the one below. Write the similarities in the space where the circles overlap and the differences on the left and right sides.



Lab zone Discover Activity

Do the Lights Keep Shining?

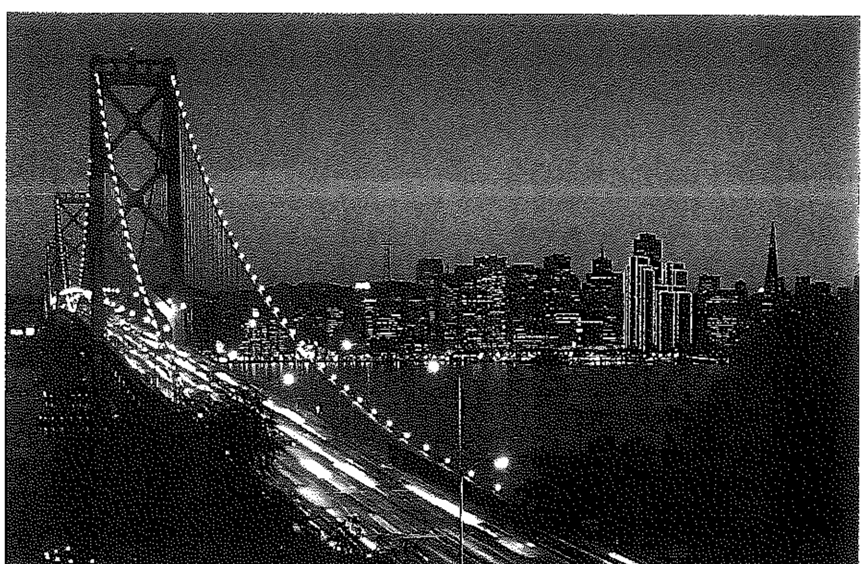
1. Construct both of the circuits shown using a battery, several insulated wires, and two light bulbs for each circuit.
2. Connect all wires and observe the light bulbs.
3. Now unscrew one bulb in each circuit. Observe the remaining bulbs.



Think It Over
Observing What happened to the remaining light bulbs when you unscrewed one bulb? How can you account for your observations?

It's a cool, clear night as you stroll along the river with your family. The city is brightly lit, and the river water sparkles with reflected light. In addition to the lights at the top of the lampposts, a string of lights borders the river path. They make a striking view.

As you walk, you notice that a few of the lights in the string are burned out. The rest of the lights, however, burn brightly. If one bulb is burned out, how can the rest of the lights continue to shine? The answer depends on how the electric circuit is designed.



Although most lights are shining, some lights are burned out. ▶

Ohm's Law

To understand electric circuits, you need to understand how current, voltage, and resistance are related to one another. In the 1800s, Georg Ohm performed experiments that demonstrated how those three factors are related. Ohm experimented with many substances while studying electrical resistance. He analyzed different types of wire in order to determine the characteristics that affect a wire's resistance.

Ohm's Results Ohm set up a circuit with a voltage between two points on a conductor. He measured the resistance of the conductor and the current between those points. Then he varied the voltage and took new measurements.

Ohm found that if the factors that affect resistance are held constant, the resistance of most conductors does not depend on the voltage across them. Changing the voltage in a circuit changes the current, but will not change the resistance. Ohm concluded that conductors and most other devices have a constant resistance regardless of the applied voltage.

Calculating With Ohm's Law The relationship between resistance, voltage, and current is summed up in **Ohm's law. Ohm's law says that the resistance is equal to the voltage divided by the current.**

This relationship can be represented by the equation below:

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

The units are ohms (Ω) = volts (V) ÷ amps (A). You can rearrange Ohm's law as follows:

$$\text{Voltage} = \text{Current} \times \text{Resistance}$$

You can use the formula to see how changes in resistance, voltage, and current are related. For example, what happens to current if voltage is doubled without changing the resistance? For a constant resistance, if voltage is doubled, current is doubled as well.

Math Skills

Decimals

When calculating voltage, you often use decimals. When you multiply two decimals, the number of decimal places in the product is the sum of the number of decimal places in each decimal you multiply.

If a circuit has a resistance of 30.5 ohms and a current of 0.05 amps, what is its voltage?

$$30.5 \text{ ohms} \times \frac{0.05 \text{ amps}}{1.525 \text{ volts}}$$

Practice Problems Use Ohm's law to calculate the voltage of a circuit with a resistance of 15.2 ohms and a current of 0.10 amps.

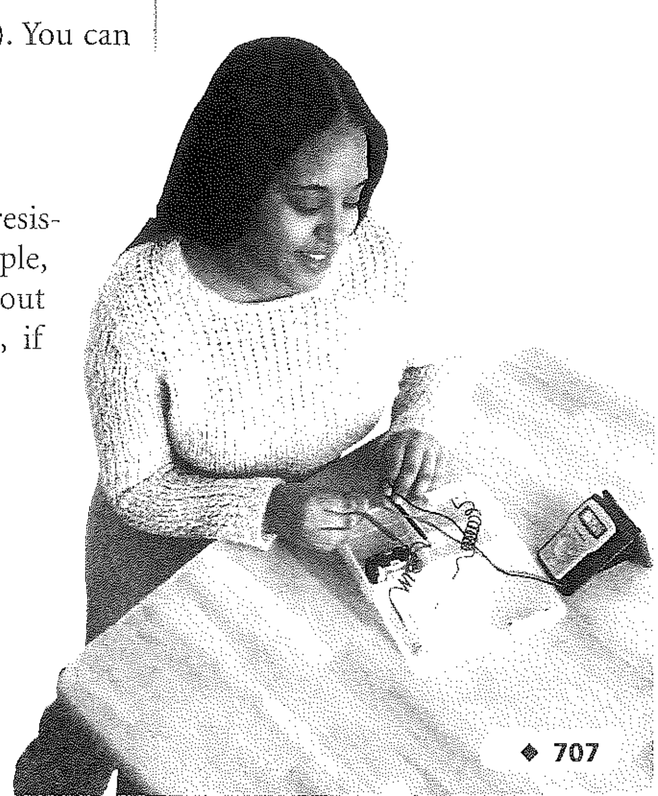


FIGURE 16
Measuring Factors in a Circuit
You can use a meter to measure voltage, current, and resistance. Measuring *What units are used to measure current and voltage?*

Math Practice

1. In a circuit, there is a 0.5-A current in the bulb. The voltage across the bulb is 4.0 V. What is the bulb's resistance?
2. A waffle iron has a 12-A current. If the resistance of the coils is 10 Ω, what must the voltage be?

Math Sample Problem

Calculating Resistance

The brake light on an automobile is connected to a 12-volt battery. If the resulting current is 0.40 amps, what is the resistance of the brake light?

1 Read and Understand

What information are you given?

Battery Voltage = 12 V

Current = 0.40 A

2 Plan and Solve

What quantity are you trying to calculate?

The resistance of the brake light.

What formula contains the given quantities and the unknown quantity?

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$

Perform the calculation.

$$\text{Resistance} = \frac{12\ \text{V}}{0.40\ \text{A}} = 30\ \Omega$$

3 Look Back and Check

Does the answer make sense?

The answer makes sense because you are dividing the voltage by a decimal. The answer should be greater than either number in the fraction, which it is.

Features of a Circuit

All electric circuits have the same basic features. **First, circuits have devices that are run by electrical energy.** A radio, a computer, a light bulb, and a refrigerator are all devices that transform electrical energy into another form of energy. A light bulb, for example, transforms electrical energy into electromagnetic energy by giving off light. The light bulb also produces thermal energy by giving off heat. By making fan blades rotate, electric fans transform electrical energy to mechanical energy. Devices such as light bulbs and fans resist the flow of electric current. They are therefore represented as resistors in a circuit.

Second, a circuit has a source of electrical energy. Batteries, generators, and electric plants all supply energy to circuits. Recall that energy is the ability to do work. The source of electrical energy makes charges move around a circuit, allowing the device to do work.

Third, electric circuits are connected by conducting wires. The conducting wires complete the path of the current. They allow charges to flow from the energy source to the device that runs on electric current and back to the energy source. A switch is often included in a circuit to control the current in the circuit. Using a switch, you can turn a device on or off by closing or opening the circuit.

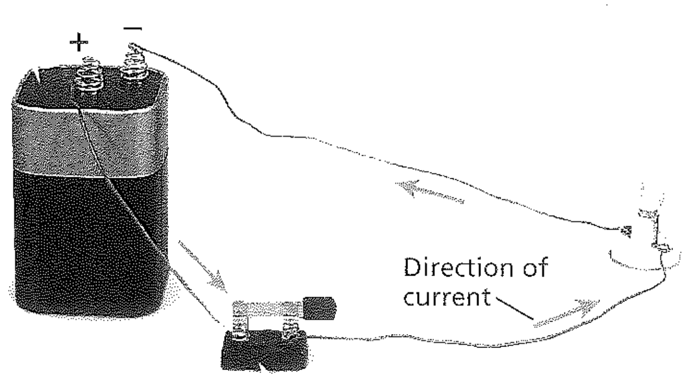
Notice that all the parts of a circuit are shown in Figure 17. Each part shown in the photograph is represented in the diagram by a simple symbol. Arrows indicate the direction of current from positive to negative. The + and – on the battery indicate the positive and negative terminals.

Reading Checkpoint **What is the function of conducting wires in a circuit?**

FIGURE 17
Diagraming a Circuit
Simple symbols make it easy to diagram a circuit. The resistor represents the device that is being run by the current. Resistors include light bulbs, appliances, and huge machines.
Interpreting Diagrams *Which symbol is used to represent a battery?*

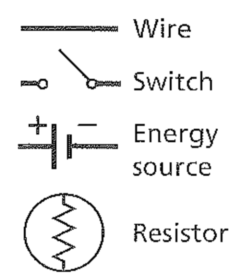
Energy Source A battery is the energy source that makes charges move around the circuit.

Resistor A light bulb is a resistor that transforms electrical energy to light.

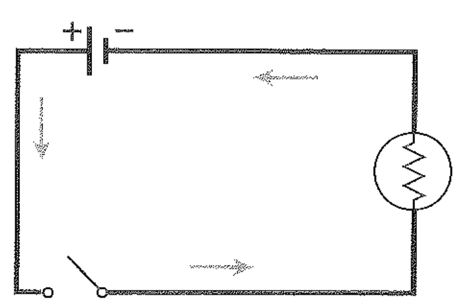


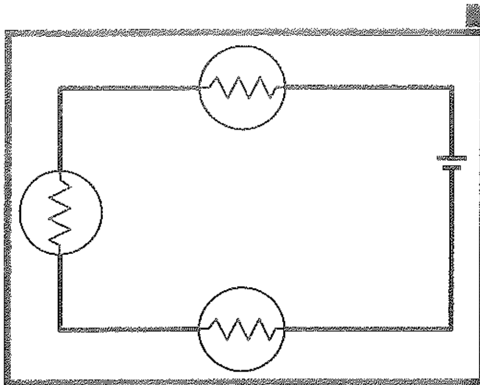
Switch A switch is used to open and close the circuit.

Circuit Symbols



Circuit Diagram





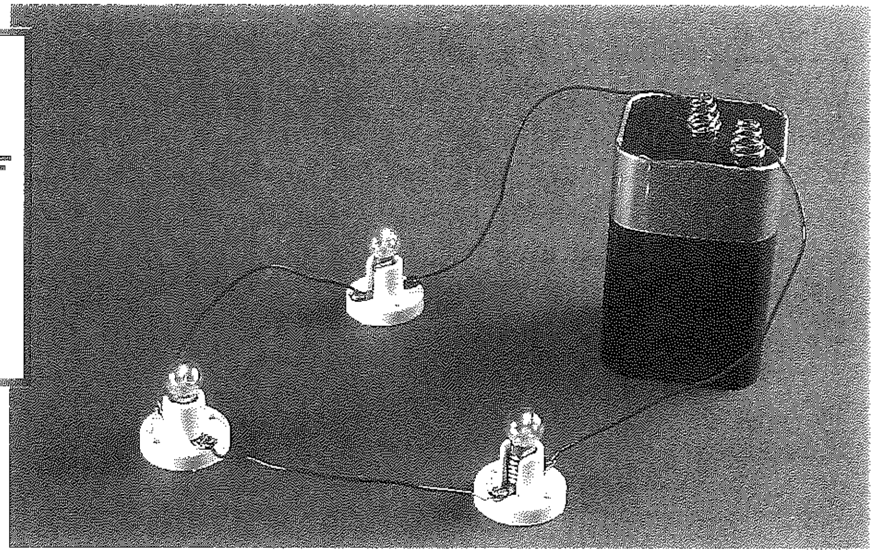


FIGURE 18
A Series Circuit
A series circuit provides only one path for the flow of electrons. Predicting *What will happen in a series circuit if one bulb burns out?*

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Series Circuits

If all the parts of an electric circuit are connected one after another along one path, the circuit is called a **series circuit.** Figure 18 illustrates a series circuit. **In a series circuit, there is only one path for the current to take.** For example, a switch and two light bulbs connected by a single wire are in series with each other.

One Path A series circuit is very simple to design and build, but it has some disadvantages. What happens if a light bulb in a series circuit burns out? A burned-out bulb is a break in the circuit, and there is no other path for the current to take. So if one light goes out, the other lights go out as well.

Resistors in a Series Circuit Another disadvantage of a series circuit is that the light bulbs in the circuit become dimmer as more bulbs are added. Why does that happen? A light bulb is a type of resistor. Think about what happens to the overall resistance of a series circuit as you add more bulbs. The resistance increases. Remember that for a constant voltage, if resistance increases, current decreases. So as light bulbs are added to a series circuit, the current decreases. The result is that the bulbs burn less brightly.

Measuring Current An **ammeter** is a device used to measure current. If you want to measure the current through some device in a circuit, the ammeter should be connected in series with that device.

Reading Checkpoint **How does resistance change as you add bulbs to a series circuit?**

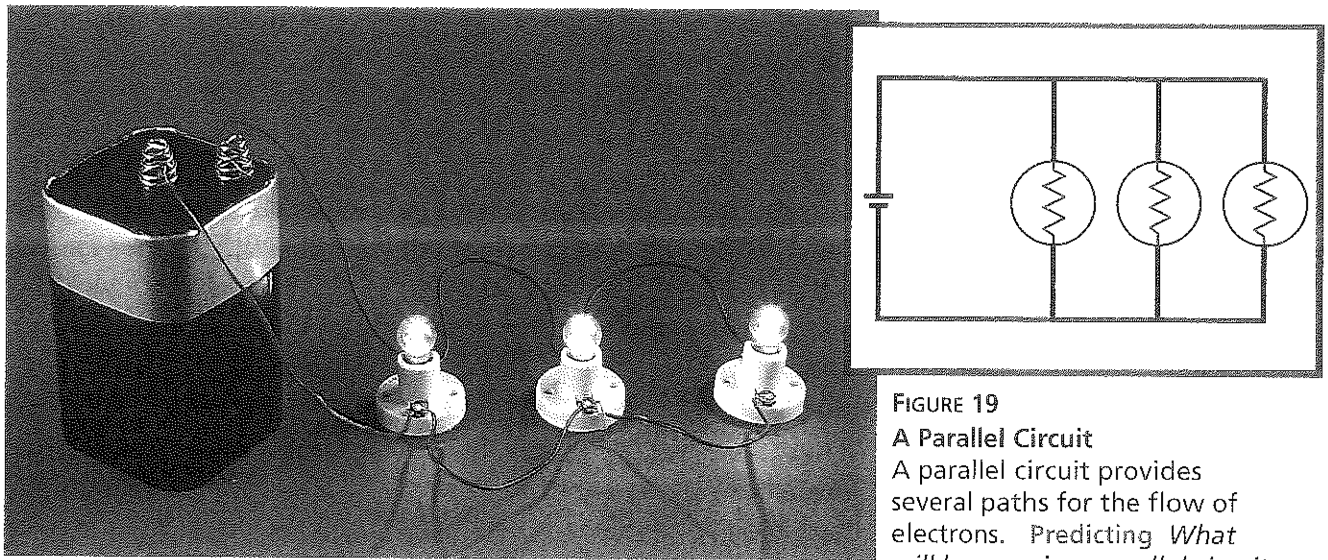


FIGURE 19
A Parallel Circuit
A parallel circuit provides several paths for the flow of electrons. **Predicting** *What will happen in a parallel circuit if one bulb burns out?*

Parallel Circuits

As you gaze at a string of lights, you observe that some bulbs burn brightly, but others are burned out. Your observation tells you that these bulbs are connected in a parallel circuit. In a **parallel circuit,** the different parts of the circuit are on separate branches. Figure 19 shows a parallel circuit. **In a parallel circuit, there are several paths for current to take.** Each bulb is connected by a separate path from the battery and back to the battery.

Several Paths What happens if a light burns out in a parallel circuit? If there is a break in one branch, charges can still move through the other branches. So if one bulb goes out, the others remain lit. Switches can be added to each branch to turn lights on and off without affecting the other branches.

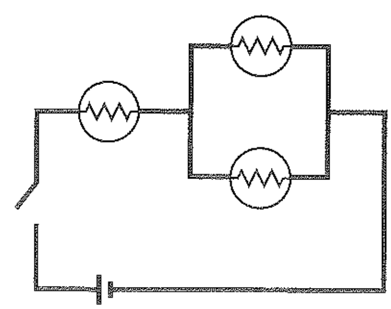
Resistors in a Parallel Circuit What happens to the resistance of a parallel circuit when you add a branch? The overall resistance actually decreases. To understand why this happens, consider blowing through a single straw. The straw resists the flow of air so that only a certain amount of air comes out. However, if you use two straws, twice as much air can flow. The more straws you have, the more paths the air has to follow. The air encounters less resistance. As new branches are added to a parallel circuit, the electric current has more paths to follow, so the overall resistance decreases.

Remember that for a given voltage, if resistance decreases, current increases. The additional current travels along each new branch without affecting the original branches. So as you add branches to a parallel circuit, the brightness of the light bulbs does not change.

Lab zone Skills Activity

Predicting

1. Look at the circuit diagram below. Predict whether all three light bulbs will shine with the same brightness.



2. Construct the circuit using a battery and three identical light bulbs. Observe the brightness of the bulbs.

Does this circuit behave like a parallel circuit or a series circuit? Explain.

Measuring Voltage A **voltmeter** is a device used to measure voltage, or electrical potential energy difference. When you measure the voltage of a device, the voltmeter and the device should be wired as a parallel circuit.

Household Circuits Would you want the circuits in your home to be series circuits? Of course not. With a series circuit, all the electrical devices in your home would stop working every time a switch was turned off or a light bulb burned out. Instead, the circuits in your home are parallel circuits.

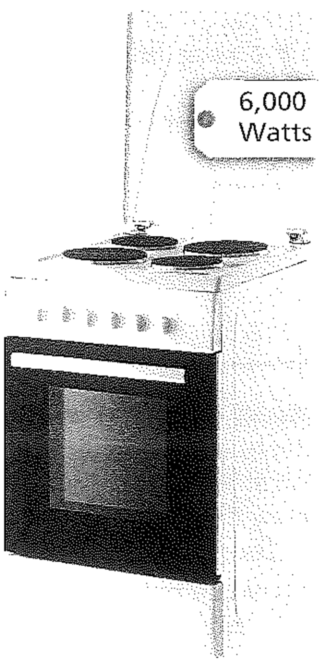
Electrical energy enters a home through heavy-duty wires. These heavy-duty wires have very low resistance. Parallel branches extend out from the heavy-duty wires to wall sockets, and then to appliances and lights in each room. Switches are installed to control one branch of the circuit at a time. The voltage in most household circuits is 120 volts.

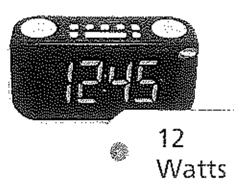
Electric Power

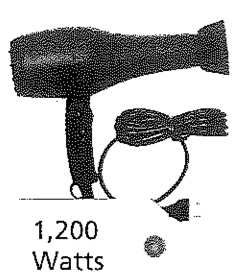
An electrical appliance transforms electrical energy into another form. The energy transformation enables the appliance to work. Hair dryers transform electrical energy to thermal energy to dry your hair. A guitar amplifier transforms electrical energy into sound. A washing machine transforms electrical energy to mechanical energy to wash your clothes. The rate at which energy is transformed from one form to another is known as **power.** The unit of power is the watt (W).

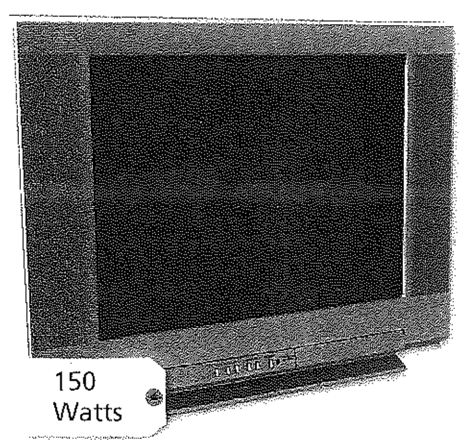
Power Ratings You are already familiar with different amounts of electric power. The power rating of a bright light bulb, for example, might be 100 W. The power rating of a dimmer bulb might be 60 W. The bright bulb transforms (or uses) electrical energy at a faster rate than the dimmer bulb.

FIGURE 20
Power Ratings
Consumers can use power rating information in buying and using appliances. **Interpreting Diagrams** *Which of the appliances shown here use the most power?*









The appliances in your home vary greatly in their power ratings. New appliances are sold with labels that show the power rating for each product. Look at Figure 20 to see typical power ratings of some common household appliances.

Calculating Power The power of a light bulb or appliance depends on two factors: voltage and current. **You can calculate power by multiplying voltage by current.**

$$\text{Power} = \text{Voltage} \times \text{Current}$$

The units are watts (W) = volts (V) × amperes (A). Using the symbols *P* for power, *V* for voltage, and *I* for current, this equation can be rewritten

$$P = VI$$

Reading Checkpoint How can you calculate power if you know the voltage and current?

Lab zone Skills Activity

Observing

Study the back or bottom of some electrical appliances around your home. Make a chart of their power ratings. Do you see any relationship between the power rating and whether or not the appliance produces heat?

Math Sample Problem

Calculating Power

A household light bulb has about 0.5 amps of current in it. Since the standard household voltage is 120 volts, what is the power rating for this bulb?

1 Read and Understand

What information are you given?

Current = 0.5 A

Voltage = 120 V

2 Plan and Solve

What quantity are you trying to calculate?

The power of the light bulb = ?

What formula contains the given quantities and the unknown quantity?

Power = Voltage × Current

Perform the calculation.

Power = 120 V × 0.5 A

Power = 60 W

3 Look Back and Check

Does your answer make sense?

The answer is reasonable, because 60 W is a common rating for household light bulbs.

Math Practice

1. A flashlight bulb uses two 1.5-V batteries in series to create a current of 0.5 A. What is the power rating of the bulb?
2. A hair dryer has a power rating of 1,200 W and uses a standard voltage of 120 V. What is the current through the hair dryer?

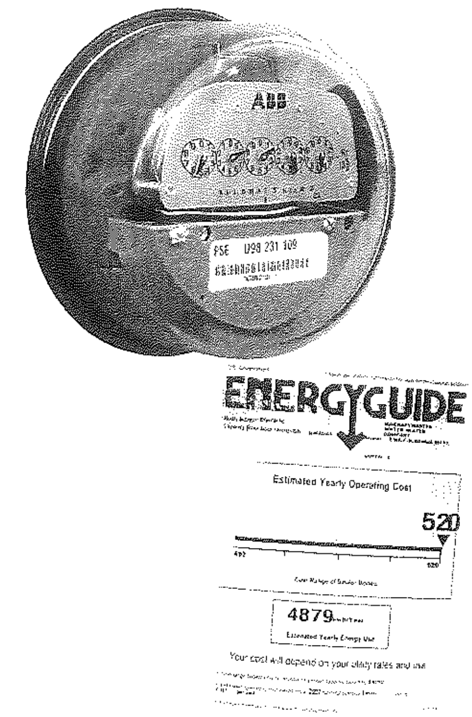


FIGURE 21
The Cost of Electrical Energy
Electric bills are based on the amount of time various appliances are used. For any appliance type, energy guides help consumers make the most efficient purchase.

Paying for Electrical Energy

The electric bill that comes to your home charges for energy use, not power. Energy use depends on both power and time. Different appliances transform electrical energy at different rates. And you use some appliances more than others. **The total amount of energy used by an appliance is equal to the power of the appliance multiplied by the amount of time the appliance is used.**

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

Electric power is usually measured in thousands of watts, or kilowatts (kW), and time is measured in hours. The unit of electrical energy is the kilowatt-hour (kWh).

$$\text{Kilowatt-hours} = \text{Kilowatts} \times \text{Hours}$$

Ten 100-watt bulbs lit for one hour use 1,000 watt-hours, or 1 kilowatt-hour, of energy.

The amount of electrical energy used in your home is measured by a meter. The electric company uses the meter to keep track of the number of kilowatt-hours used. You pay a few cents for each kilowatt-hour.

Section 4 Assessment

Target Reading Skill

Comparing and Contrasting Use the information in your Venn diagram about series and parallel circuits to help you answer Question 3.

Reviewing Key Concepts

1. a. **Reviewing** What three related electrical factors did Georg Ohm investigate?
   b. **Explaining** What relationship did Ohm discover between these three factors?
   c. **Predicting** In a circuit with a constant resistance, what will happen to the current if the voltage is multiplied four times?
2. a. **Listing** List three basic features of an electric circuit.
   b. **Interpreting Diagrams** How is each feature represented in the circuit diagram in Figure 17?
3. a. **Comparing and Contrasting** Compare and contrast series and parallel circuits.
   b. **Relating Cause and Effect** If you remove one bulb from a string of lights, all the remaining lights will go out. Are the lights in a series circuit or parallel circuit? Explain.
4. a. **Defining** What is electric power?
   b. **Calculating** What formula can you use to calculate power?
   c. **Making Generalizations** Is it true that the bigger the electrical device, the greater its power rating? Use Figure 20 to explain your answer.

Math Practice

5. **Calculating Resistance** The current through a resistor is 0.025 A when it is connected to a 10.0-V source. What is the resistance?
6. **Calculating Power** A refrigerator uses a standard voltage of 120 V and has a current of about 4.2 A. What is its power rating?

Section 5

Integrating Health

Electrical Safety

Reading Preview

Key Concepts

- What measures help protect people from electrical shocks and short circuits?

Key Terms

- short circuit
- grounded
- third prong
- fuse
- circuit breaker

Target Reading Skill

Using Prior Knowledge Before you read, write what you know about electrical safety in a graphic organizer like the one below. As you read, write what you learn.

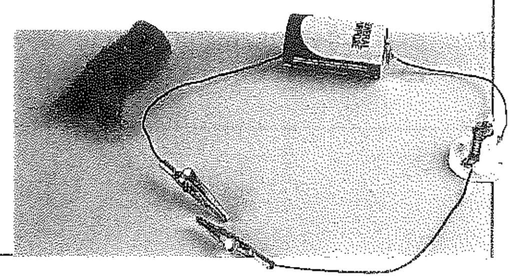
What You Know
1. An electric shock can be dangerous. 2.

What You Learned
1. 2.

Lab zone Discover Activity

How Can You Blow a Fuse?

1. Begin by constructing the circuit shown using a D-cell, a light bulb, and two alligator clips.
2. Pull a steel fiber out of a piece of steel wool. Wrap the ends of the steel fiber around the alligator clips.
3. Complete the circuit and observe the steel fiber and the bulb.



Think It Over

Developing Hypotheses Write a hypothesis to explain your observations.

The ice storm has ended, but it has left a great deal of destruction in its wake. Trees have been stripped of their branches, and a thick coating of ice covers the countryside. Perhaps the greatest danger is from the downed high-voltage electric wires. Residents are being warned to stay far away from them. What makes these high-voltage wires so dangerous?

Personal Safety

You may have noticed high-voltage wires hanging from poles beside the highway. These wires form a circuit to and from the electric plant. The wires carry electric current from the electric plant to the customer. If these wires are damaged, they can cause serious injury. Potential dangers include short circuits, electric shocks, and ungrounded wires.

Short Circuits If someone touches a downed electric wire, the person's body can form a short circuit between the wire and the ground. A short circuit can also occur in your home if you touch frayed wires. A **short circuit** is a connection that allows current to take the path of least resistance. For example, the electric charge can flow through the person rather than through the wire to the power plant. The unintended path usually has less resistance than the intended path. Therefore, the current can be very high. The shock that the person receives may be fatal.

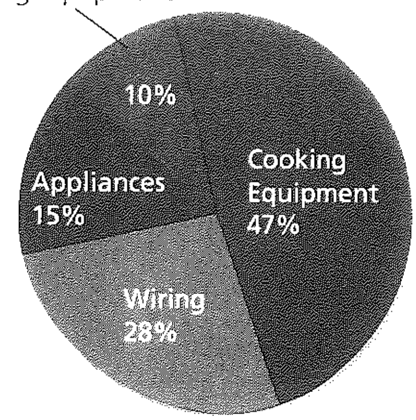
Math Analyzing Data

Electrical Equipment and Fires

If electrical equipment is not properly used and maintained, it can cause fires. The circle graph shows the percentage of fires caused by different types of electrical equipment.

1. Reading Graphs What determines the size of each wedge in the graph?
2. Reading Graphs What percentage of fires are caused by appliances?
3. Interpreting Data Which category of equipment is responsible for most fires? Which category is responsible for the fewest fires?

Fires From Electrical Equipment



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For: Links on electric safety
Visit: www.SciLinks.org
Web Code: scn-1426

Electric Shocks Electrical signals in the human body control breathing, heartbeat, and muscle movement. If your body receives an electric current from an outside source, it can result in a shock that interferes with your body's electrical signals.

The shock you feel from static discharge after walking across a carpet is very different from the shock that could come from touching a fallen high-voltage wire. The severity of an electric shock depends on the current. A current of less than 0.01 A is almost unnoticeable. But a current greater than 0.2 A can be dangerous, causing burns or even stopping your heart.

Grounding Earth plays an important role in electrical safety. **One way to protect people from electric shock and other electrical danger is to provide an alternate path for electric current.** Most buildings have a wire that connects all the electric circuits to the ground, or Earth. A circuit is electrically **grounded** when charges are able to flow directly from the circuit into Earth in the event of a short circuit.

One method of grounding is to use a third prong on a plug. Two flat prongs of a plug connect an appliance to the household circuit. The **third prong**, which is round, connects any metal pieces of the appliance to the ground wire of the building. If a short circuit occurs in the appliance, the electric charge will flow directly into Earth. Any person who touches the device will be protected.

Reading Checkpoint **What is the function of a third prong?**

The ground prong connects the metal shell of an appliance to the ground wire of a building.

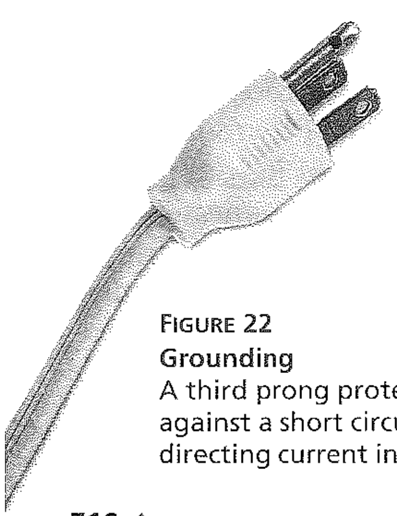


FIGURE 22
Grounding
A third prong protects against a short circuit by directing current into Earth.

Breaking a Circuit

If you use too many appliances at once, a circuit's current can become dangerously high and heat the wires that carry it. Overloading a circuit can result in a fire. **In order to prevent circuits from overheating, devices called fuses and circuit breakers are added to circuits.**

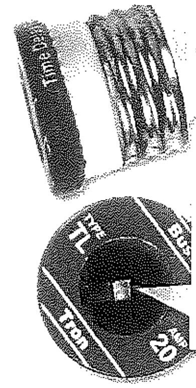
A **fuse** is a device that contains a thin strip of metal that will melt if there is too much current through it. When the strip of metal "blows," or melts, it breaks the circuit. The breaking of the circuit stops the current. Fuses are commonly found in cars and older buildings. Figure 23 shows how a fuse works.

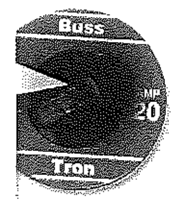
A disadvantage of using a fuse is that once it burns out, it must be replaced. To avoid the task of replacing fuses, circuits in new buildings are protected by devices called circuit breakers. A **circuit breaker** is a reusable safety switch that breaks the circuit when the current gets too high. In some circuit breakers, a high current causes a small metal band to heat up. As the band heats up it bends away from wires in the circuit, disrupting the current.

It's easy to reset the circuit breaker. By pulling the switch back, you reconnect the metal band to the wires. However, the appliances that are causing the high current in the circuit need to be turned off first.

Reading Checkpoint **What is the difference between a fuse and a circuit breaker?**

FIGURE 23
A Fuse
When a circuit becomes overloaded, a fuse stops the current. Interpreting Diagrams *How does a fuse work?*





Section 5 Assessment

Target Reading Skill Using Prior Knowledge Review your graphic organizer about electrical safety and revise it based on what you have just learned in the section.

Reviewing Key Concepts

1. a. Defining What are grounded electric circuits? What are fuses and circuit breakers?
   b. Explaining Explain how grounding, fuses, and circuit breakers protect people from electrical shocks and short circuits.
   c. Predicting Without a fuse or circuit breaker, what might happen in a house with an overloaded electric circuit? Explain your answer.

Lab zone At-Home Activity

Checking Circuits Along with members of your family, find out whether the circuits in your home are protected by fuses or circuit breakers. **CAUTION:** *Be careful not to touch the wiring during your inspection.* How many circuits are there in your home? Make a diagram showing the outlets and appliances on each circuit. Explain the role of fuses and circuit breakers. Ask your family members if they are aware of these devices in other circuits, such as in a car.

Chapter 20 Study Guide

The BIG Idea **Transfer of Energy** Electric current is the continuous flow of energy in the form of electric charges through a wire or similar material.

1 Electric Charge and Static Electricity

Key Concepts

- Charges that are the same repel each other. Charges that are different attract each other.
- An electric field is a region around a charged object where the object's electric force interacts with other charged objects.
- Static electricity charge builds up on an object but does not flow continuously. Static electricity is transferred through charging by friction, by conduction, and by induction.
- When negatively and positively charged objects are brought together, electrons transfer until both objects have the same charge.

Key Terms

• electric force • electric field • static electricity
• conservation of charge • friction
• conduction • induction • static discharge

2 Electric Current

Key Concepts

- To produce electric current, charges must flow continuously from one place to another.
- A conductor transfers electric charge well. An insulator does not transfer electric charge well.
- Voltage causes a current in an electric circuit.
- The greater the resistance, the less current there is for a given voltage.

Key Terms

• electric current • electric circuit • conductor
• insulator • voltage • voltage source
• resistance

3 Batteries

Key Concepts

- Volta built the first battery by layering zinc, paper soaked in salt water, and silver.
- Chemical reactions in an electrochemical cell cause one electrode to be negatively charged and the other to be positively charged.

Key Terms

• chemical energy • chemical reaction
• electrochemical cell • electrode • electrolyte
• terminal • battery • wet cell • dry cell

4 Electric Circuits and Power

Key Concepts

- Ohm's law says that:

$$\text{Resistance} = \text{Voltage} \div \text{Current}$$

- Circuits have a source of electrical energy and devices that are run by electrical energy. Circuits are connected by conducting wires.
- In a series circuit, there is only one path for the current to take. In a parallel circuit, there are several paths for the current to take.
- You can calculate power by multiplying voltage by current.
- The total amount of energy used by an appliance is equal to its power multiplied by the amount of time it is used.

Key Terms

• Ohm's law • series circuit • ammeter
• parallel circuit • voltmeter • power

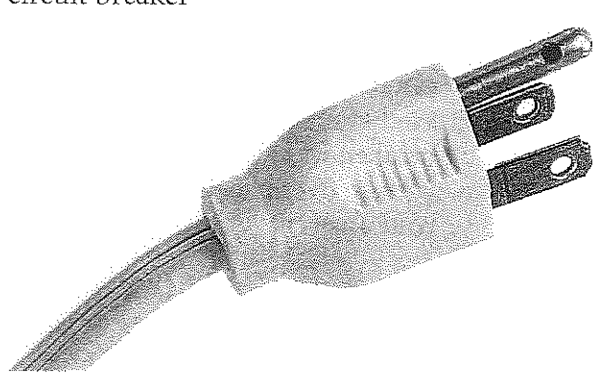
5 Electrical Safety

Key Concepts

- One way to protect people from electric shock and other electrical danger is to provide an alternate path for electric current.
- In order to prevent circuits from overheating, devices called fuses and circuit breakers are added to circuits.

Key Terms

• short circuit • grounded • third prong
• fuse • circuit breaker



Review and Assessment

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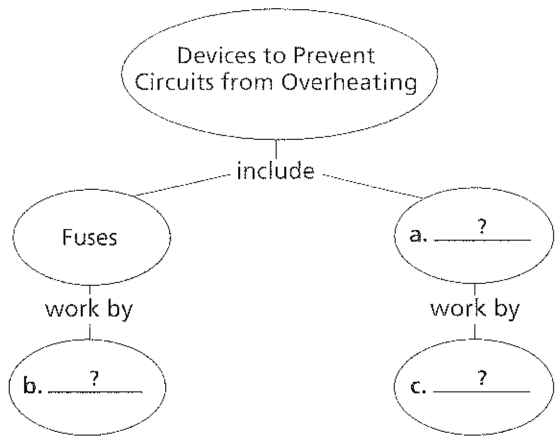
Organizing Information

Concept Mapping Copy the concept map about devices that prevent circuits from overheating. Then complete the concept map. (For more information on concept maps, see the Skills Handbook.)



Reviewing Key Terms

Choose the letter of the best answer.

1. The attraction or repulsion between electric charges is called a(n)
   a. electric field.
   b. electric force.
   c. electron.
   d. static electricity.
2. The potential difference that causes charges to move in a circuit is called
   a. current.
   b. electric discharge.
   c. resistance.
   d. voltage.
3. A combination of two or more electrical cells in a series is called a(n)
   a. wet cell.
   b. dry cell.
   c. battery.
   d. electrode.
4. A device that measures electric current is a(n)
   a. ammeter.
   b. battery.
   c. resistor.
   d. voltmeter.
5. Connecting a circuit to Earth as a safety precaution is called
   a. a short circuit. b. an insulator.
   c. grounding. d. static discharge.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

6. Conduction is the process of charging an object without touching it.
7. Electrical resistance is low in a good conductor.
8. An electrolyte is an attachment point used to connect a cell or battery to a circuit.
9. In a series circuit, all parts of the circuit are connected in a single path.
10. Power is the rate at which energy is transformed from one form to another.

Writing in Science

Descriptive Paragraph Describe the journey of an electron in a lightning bolt. Begin at the thundercloud and follow the path of the electron until the lightning bolt strikes the ground.

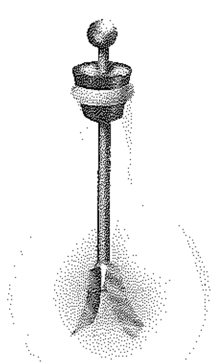
Review and Assessment

Checking Concepts

11. Describe the three ways in which an object can become charged.
12. What units are used to measure voltage, current, and resistance?
13. Explain how the components of an electrochemical cell produce voltage.
14. What is Ohm's law?
15. What would happen if the circuits in your school building were series circuits? Explain.
16. Which glows more brightly—a 100-W bulb or a 75-W bulb? Explain your answer.
17. What is a short circuit?

Thinking Critically

18. Classifying Identify each of the following statements as characteristic of series circuits, parallel circuits, or both:
    a. Current = Voltage ÷ Resistance
    b. Total resistance increases as more light bulbs are added.
    c. Total resistance decreases as more branches are added.
    d. Current in each part of the circuit is the same.
    e. A break in any part of the circuit will cause current to stop.
19. Interpreting Diagrams Is the electroscope shown below charged or uncharged? Explain.



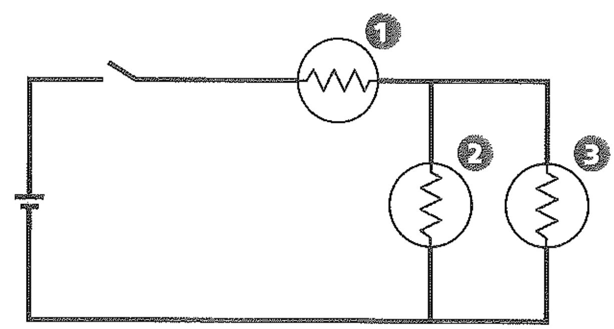
20. Applying Concepts Explain why the third prong of a plug should not be removed.
21. Comparing and Contrasting Compare and contrast wet cells and dry cells.

Math Practice

22. Calculating Resistance A toaster is plugged into a 120-volt socket. If it has a current of 0.25 amps in its coils, what is the resistance of the toaster? Show your work.
23. Calculating Power The voltage of a car battery is 12 volts. When the car is started, the battery produces a 40-amp current. How much power does it take to start the car?

Applying Skills

Use the diagram below for Questions 24–27.



24. Classifying Is the circuit in the illustration a series or parallel circuit? Explain.
25. Controlling Variables Would the other bulbs continue to shine if you removed bulb 1? Would they shine if you removed bulb 2 instead? Explain your reasoning.
26. Predicting Will any of the bulbs be lit if you open the switch? Explain.
27. Making Models Redraw the circuit diagram to include a switch that controls only Bulb 3.

Lab zone Chapter Project

Performance Assessment Prepare a description and circuit diagram for your display. If any parts of your alarm circuit are not visible, draw a second diagram showing how all the parts are assembled. Then present your alarm to your class and explain how it could be used. Include a description of the reliability of your switch.

Standardized Test Prep

Test-Taking Tip

Using Formulas

Some test questions require you to use a formula. Find out what you are being asked to determine. Then recall formulas and other information necessary to answer the question. To solve for a specific quantity in the formula, substitute the known values for the variables.

Sample Question

Your alarm clock has a voltage of 120 V and a resistance of 1,200 Ω. What is the current?

A 0.10 A
B 10.0 A
C 12.0 A
D 100 A

Answer

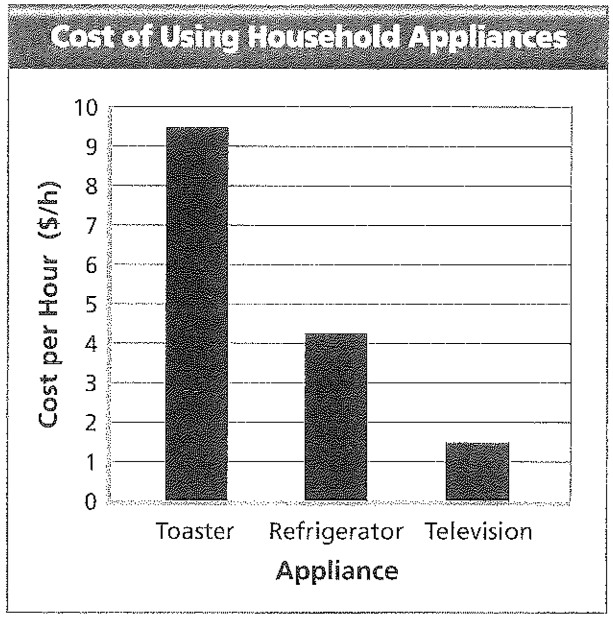
The answer is A. To find the current, you use the formula for Ohm's law, which is Resistance = Voltage ÷ Current. The rearranged formula is Current = Voltage ÷ Resistance. Divide the voltage (120 V) by the resistance (1,200 Ω).

Choose the letter of the best answer.

1. Which of the following is a reusable device that protects a circuit from becoming overheated?
   A a circuit breaker
   B a third prong
   C a fuse
   D an electroscope

2. You want to build a device that can conduct current but that will be safe if touched by a person. Which of the following pairs of materials could you use?
   F glass for the conductor and rubber for the insulator
   G copper for the insulator and silver for the conductor
   H sand for the conductor and plastic for the insulator
   J plastic for the insulator and silver for the conductor

3. The graph shows the cost of using three household appliances. Which of the following is a valid interpretation of the graph?



   A A toaster has high voltage.
   B It costs more per hour to run a refrigerator than a television.
   C During a month, a family pays more to run a toaster than a refrigerator.
   D A toaster uses more current than any other appliance.

4. An electrochemical cell has one copper nail and one zinc nail. When the nails are placed in vinegar, the light bulb lights up. What conclusion can be made?
   F No chemical reaction occurred.
   G Vinegar is an electrolyte.
   H All electrochemical cells contain vinegar.
   J The zinc nail reacted with the vinegar but the copper nail did not.

Constructed Response

5. Explain why people should never touch a high-voltage wire that has blown down in a storm. In your explanation, use the words *electric shock* and *short circuit*.