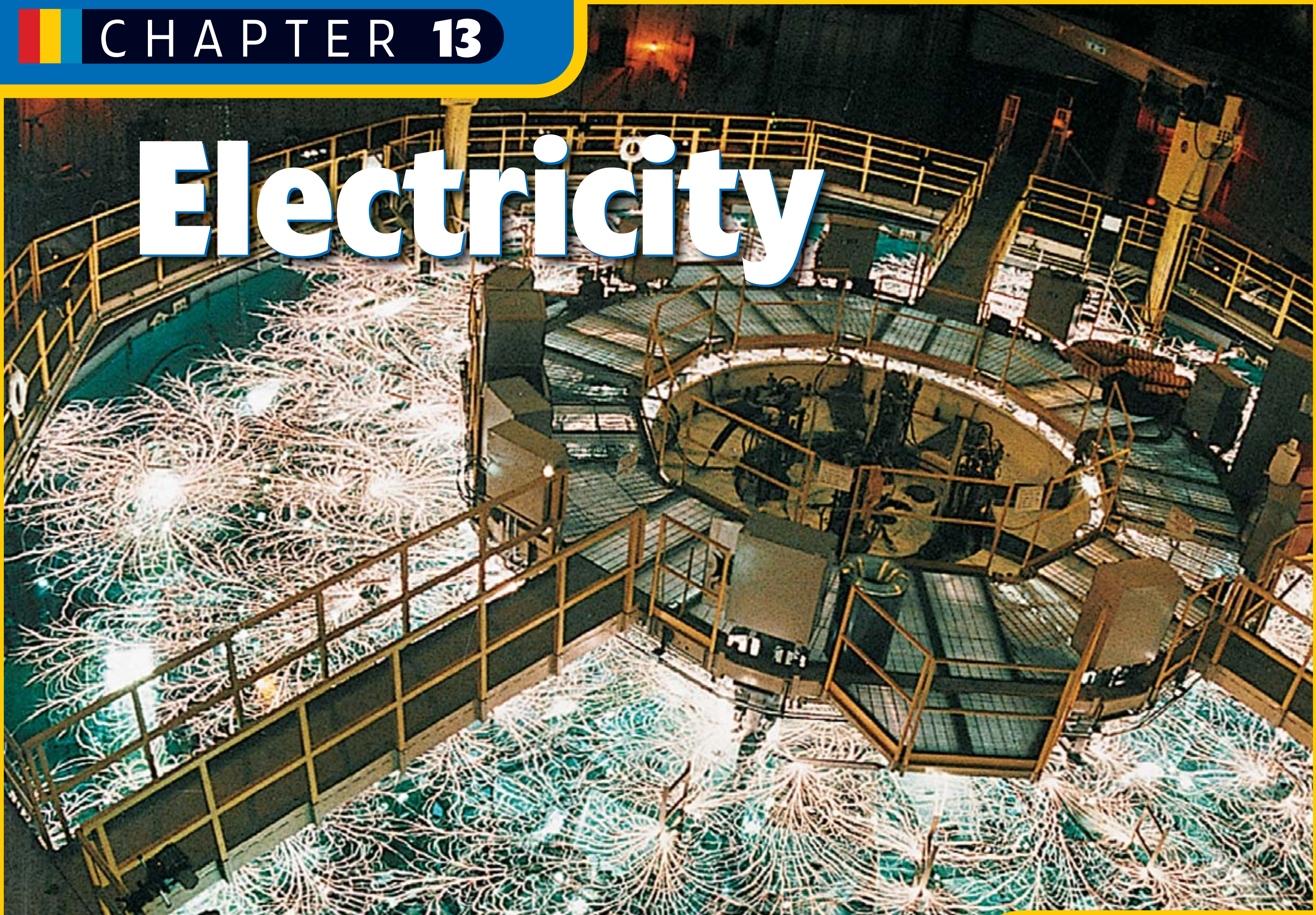
CHAPTER 13

Electricity



Chapter Preview

Electricity arcs across the fusion chamber at Sandia National Laboratory in the large photo above. Video games and all other electrical appliances use the movement of electrons to operate.

Back

Focus ACTIVITY

Background A race car rounds a curve and speeds to the finish line in first place. Afterward, the screen darkens and the driver's score is displayed. Video games let you pretend to drive race cars, fly airplanes, and fight warriors. They are complex pieces of electrical equipment with a detailed video display and computer chips that use electric power supplied by a power plant miles away. And in turn, that energy comes from burning fossil fuels, falling water, the wind, or nuclear fission.

At the Sandia National Laboratory, in New Mexico, powerful electrical arcs are generated in a split second when scientists fire a fusion device. Each electrical arc is similar to a bolt of lightning. A huge number of electrons move across the chamber with each arc. Although they cannot be seen, electrons move inside all electrical devices, including video games. Without electricity, we couldn't make telephone calls, use computers, watch television, or ride in high-speed trains. But electricity is not just important in technology; it is also a vital part of the natural world and every living organism.

Activity 1 Remove the bulb and battery from a flashlight. Can you use the bulb, battery, and a small piece of wire or some aluminum foil to make the light bulb light up? Try connecting the light bulb to the battery in several different ways. What makes the light bulb light up?

Activity 2 Find your electric meter at home. Observe how the horizontal gear moves and the numbers on the dials change. If you have an electric clothes dryer or air conditioner, observe the dials on the meter when one of these appliances is operating. Compare this with the rate of movement of the dials when all the electrical appliances and lights are turned off. Based on your results, what do you think the electric meter measures?

internetconnect

SciLINKS NSTA

TOPIC: Applications of the electric spark
GO TO: www.scilinks.org
KEYWORD: HK1131

Electric Charge and Force

KEY TERMS

electric charge
conductor
insulator
electric force
electric field

OBJECTIVES

- Indicate which pairs of charges will repel and which will attract.
- Explain what factors affect the strength of the electric force.
- Describe the characteristics of the electric field due to a charge.

When you speak into a telephone, the microphone in the handset changes your sound waves into electric signals. Light shines in your room when you flip a switch. And if you step on a pin with bare feet, your nerves send messages back and forth between your brain and your muscles so that you react quickly. These messages are carried by electric pulses moving through your nerve cells.

PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc Two, Module 15:
Force Between Charges
Use the Interactive Tutor to learn more about this topic.

Electric Charge

You have probably been shocked from touching a doorknob after walking across a rug on a dry day. This happens because your body picks up **electric charge** as your shoes move across the carpet. Although you may not notice these charges when they are spread throughout your body, you notice them as they pass from your finger to the metal doorknob. You experience this movement of charges as a shock.

electric charge an electrical property of matter that creates a force between objects

Like charges repel, and opposite charges attract

One way to observe charge is to rub a balloon back and forth across your hair. You may find that the balloon is attracted to your hair, as shown in **Figure 13-1A.** If you rub two balloons across your hair and then gently bring them near each other, as shown in **Figure 13-1B,** the balloons will push away from, or repel, each other.

Figure 13-1

A If you rub a balloon across your hair on a dry day, the balloon and your hair become charged and are attracted to each other.

B The two charged balloons, on the other hand, repel one another.

Back

After this experiment, the balloons and your hair have some kind of charge on them. Your hair is attracted to both balloons, yet the two balloons are repelled by each other. This means there must be two types of charges—the type on the balloons and the type on your hair.

The two balloons must have the same kind of charge because each became charged in the same way. Because the two charged balloons repel each other, we see that like charges repel. However, a rubbed balloon and your hair, which did not become charged in the same way, are attracted to one another. This is because unlike charges attract.

The two types of charges are called *positive* and *negative*. When you rub a balloon on your hair, the charge on your hair is positive and the charge on the balloon is negative. When there is an equal amount of positive and negative charges on an object, it has no net charge.

An object's electric charge depends on the imbalance of its protons and electrons

Recall from Section 3.1 that all matter, including you, is made up of atoms. Atoms in turn are made up of even smaller building blocks—electrons, protons, and neutrons. Electrons are negatively charged, protons are positively charged, and neutrons are neutral (no charge).

Objects are made up of an enormous number of neutrons, protons, and electrons. Whenever there is an imbalance in the number of protons and electrons in an atom, molecule, or other object, it has a net electric charge. The difference in the numbers of protons and electrons determines an object's electric charge. Negatively charged objects have more electrons than protons. Positively charged objects have fewer electrons than protons.

The SI unit of electric charge is the *coulomb,* C. The electron and proton have exactly the same amount of charge, 1.6×10^{-19} C. Because they are oppositely charged, a proton has a charge of $+1.6 \times 10^{-19}$ C, and an electron has a charge of -1.6×10^{-19} C. An object with a total charge of -1.0 C has 6.25×10^{18} excess electrons. Because the amount of electric charge on an object depends on the numbers of protons and electrons, the net electric charge of a charged object is always a multiple of 1.6×10^{-19} C.

Connection to SOCIAL STUDIES

Benjamin Franklin (1706–1790) first suggested the terms *positive* and *negative* for the two different types of charge.

At the age of 40, Franklin was a successful printer and journalist. He saw some experiments on electricity and was so fascinated by them that he began to devote much of his time to experimenting.

Franklin was the first person to realize that lightning is a huge electric discharge, or spark. He invented the first lightning rod, for which he became famous. He also flew a kite into thunderclouds—at great risk to his life—to collect charge from them.

During and after the Revolutionary War, Franklin gained fame as a politician and statesman.

Making the Connection

1. Franklin is credited with many famous inventions besides his groundbreaking electricity experiments. Prepare a presentation in the form of a skit, story, or computer program about his work on fire departments, public libraries, or post offices.
2. One of Franklin's other technological achievements was the invention of the Franklin stove. Research this stove, and write a brochure explaining the benefits of this stove to prospective customers of Franklin's time.

WRITING SKILL

internetconnect

SCILINKS NSTA

TOPIC: Static electricity
GO TO: www.scilinks.org
KEYWORD: HK1132

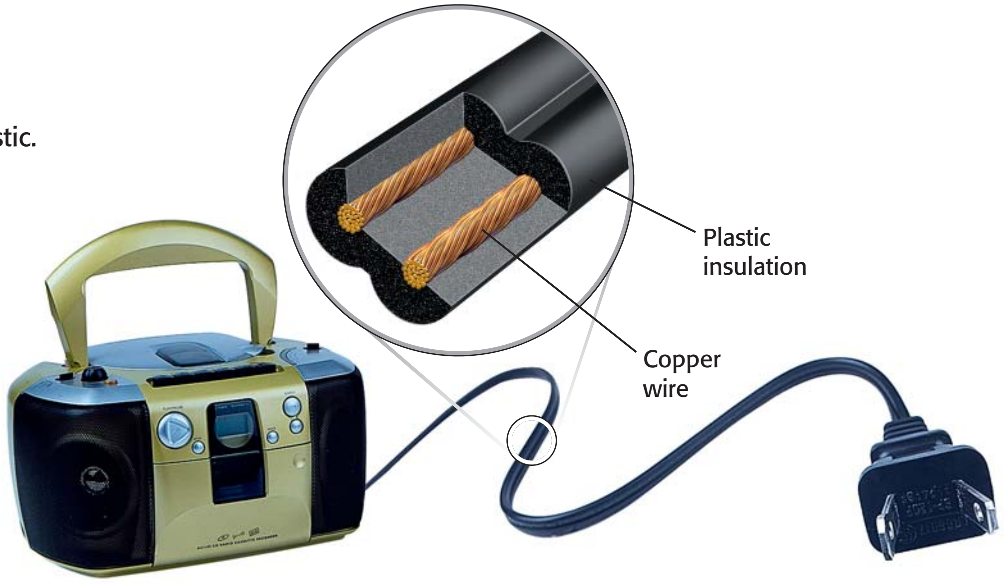


Figure 13-2
Appliance cords are made of metal wire surrounded by plastic. Electric charges move easily through the wire, but the plastic insulation prevents them from leaking into the surroundings.

Conductors allow charges to flow; insulators do not

Have you ever noticed that the electric cords attached to appliances, such as the stereo shown in **Figure 13-2,** are plastic? These cords are not plastic all the way through, however. The center of an electric cord is made of thin copper wires twisted together. Cords are layered like this because of the electric properties of each material.

Materials like the metal in cords are called **conductors.** Conductors allow electric charges to move relatively freely. The plastic in the cord, however, does not allow electric charges to move freely. Materials that do not transfer charge easily are called **insulators.** Cardboard, glass, silk, and plastic are insulators.

Charges in the electric cord attached to an appliance can move through the conducting center but cannot escape through the surrounding insulator. This design makes the appliances more efficient and helps protect people from dangerous electric shock.

conductor a material that transfers charge easily

insulator a material that does not transfer charge easily

INTEGRATING

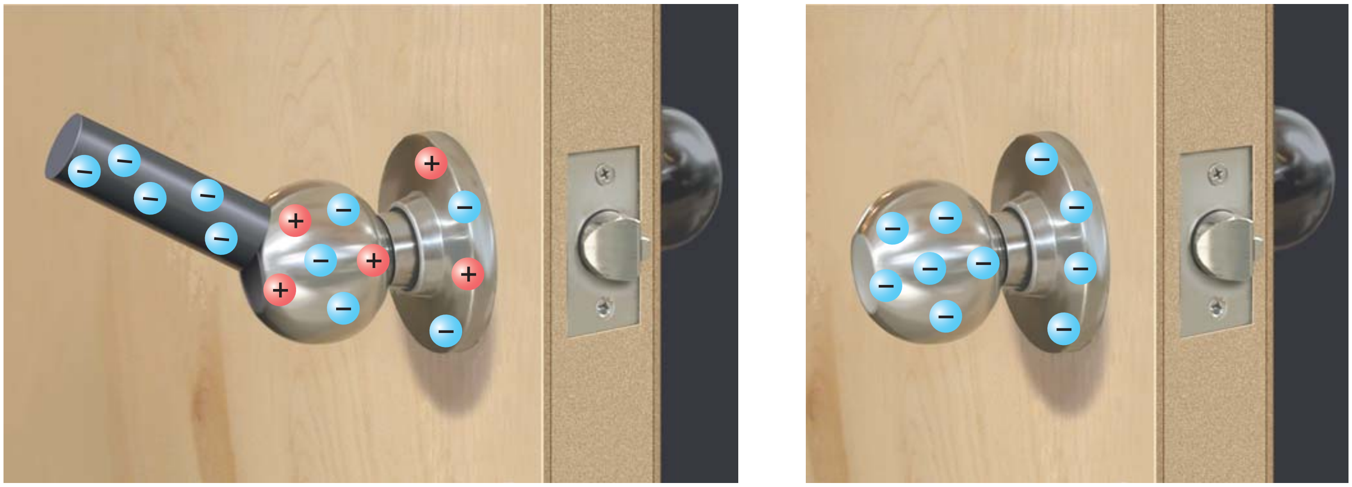
BIOLOGY
All living cells contain ions. Most cells also need to be bathed in solutions of ions to stay alive. As a result, most living things are fairly good conductors.

Dry skin can be a good insulator. But if your skin gets wet it becomes a conductor, and charge can move through your body more easily. So there is a greatly increased risk of electrocution when your skin is wet.

Objects can be charged by the transfer of electrons

Protons and neutrons are relatively fixed in the nucleus of the atom, but the outermost electrons can be easily transferred from one atom to another. When different materials are rubbed together, electrons can be transferred from one material to the other. The direction in which the electrons are transferred depends on the materials.

For example, when you slide across a fabric car seat, some electrons are transferred between your clothes and the car seat. Depending on the types of materials involved, the electrons can be transferred from your clothes to the seat or from the seat to your clothes. One material gains electrons and becomes negatively charged, and the other loses electrons and becomes positively charged. This is an example of *charging by friction.*



A B

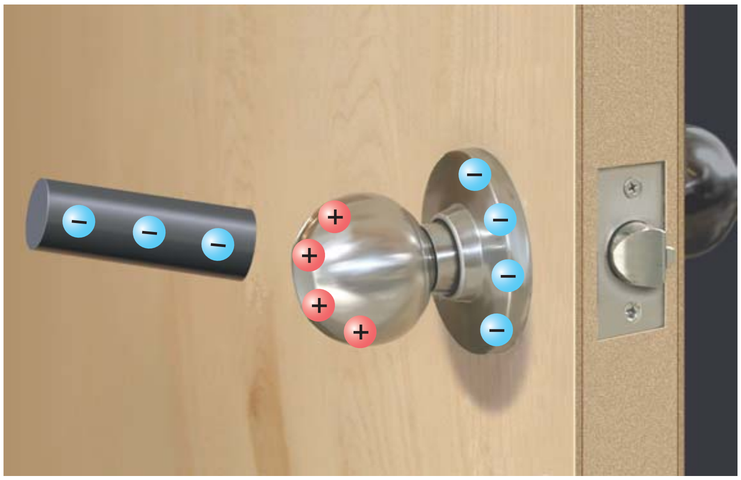
Figure 13-3
(A) When a negative rod touches a neutral doorknob, electrons move from the rod to the doorknob.
(B) The transfer of electrons to the metal doorknob gives the doorknob a net negative charge.

Objects can also be charged without friction. One way to charge a neutral object without friction is by touching it with a charged object. As shown in **Figure 13-3A,** when the negatively charged rubber rod touches a neutral object, like the doorknob, some electrons move from the rod to the doorknob. The doorknob then has a net negative charge, as shown in **Figure 13-3B.** The rubber rod still has a negative charge, but the charge is smaller. If a positively charged rod touches a neutral doorknob, electrons move into the rod from the neutral doorknob, giving the doorknob a positive charge. Objects charged in this manner are said to be charged by *contact*.

Charges move within uncharged objects

The charges in a neutral conductor can be redistributed without contacting a charged object. If you just bring a negatively charged rubber rod close to the doorknob, the movable electrons in the doorknob will be repelled. Because the doorknob is a conductor, the electrons will move away from the rod. As a result, the portion of the doorknob closest to the negatively charged rod will have an excess of positive charge. The portion farthest from the rod will have a negative charge. But the doorknob will be neutral. Although the total charge on the doorknob will be zero, the opposite sides will have an *induced* charge, as shown in **Figure 13-4.**

Figure 13-4
A negatively charged rod brought near a metal doorknob induces a positive charge on the side of the doorknob closest to the rod and a negative charge on the side farthest from the rod.



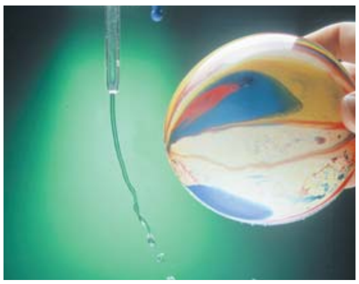
Back

Figure 13-5
The negatively charged comb induces a positive charge on the surface of the tissue paper closest to the comb, so the comb and the paper are attracted to each other.

Quick ACTIVITY

Charging Objects

1. Rub two air-filled balloons vigorously on a piece of wool.
2. Hold your balloons near each other.
3. Now try to attach one balloon to the wall.
4. Turn on a faucet, and hold a balloon near the stream of tap water.
5. Explain what happens to the charges in the balloons, wool, water, and wall.



How can the negatively charged comb in **Figure 13-5** pick up pieces of neutral tissue paper? The electrons in tissue paper cannot move about freely because the paper is an insulator. But when a charged object is brought near an insulator, the positions of the electrons within the individual molecules of the insulator change slightly. One side of a molecule will be slightly more positive or negative than the other side. This *polarization* of the atoms or molecules of an insulator produces an induced charge on the surface of the insulator. The surface of the tissue paper nearest the comb has an induced positive charge. The surface farthest from the comb has an induced negative charge.

Electric Force

The attraction of tissue paper to a negatively charged comb and the repulsion of the two balloons are examples of **electric force.** It is also the reason clothes sometimes cling to each other when you take them out of the dryer. Such pushes and pulls between charges are all around you. For example, a table feels solid, even though its atoms contain mostly empty space. The electric force between the electrons in the table's atoms and your hand is strong enough to prevent your hand from going through the table. In fact, the electric force at the atomic and molecular level is responsible for most of the common forces we can observe, such as the force of a spring and the force of friction.

The electric force is also responsible for effects that we can't see; it is part of what holds an atom together. The bonding of atoms to form molecules is also due to the electric force. The electric force plays a part in the interactions among molecules, such as the proteins and other building blocks of our bodies. Without the electric force, life itself would be impossible.

electric force the force of attraction or repulsion between objects due to charge

Back

Electric force depends on charge and distance

The electric force between two charged objects varies depending on the amount of charge on each object and the distance between them. The electric force between two balloons is proportional to the product of the charges on the balloons.

The electric force is inversely proportional to the square of the distance between two objects. For example, if the distance between two charged balloons is doubled, the electric force between them decreases to one-fourth its original value. If the distance between two charged balloons is quadrupled, the electric force between them decreases to one-sixteenth its original value. Chapter 8 showed that the gravitational force depends on distance in the same way.

Electric force acts through a field

As described earlier, electric force does not require that objects touch. How do charges interact over a distance? One way to model this property of charges is with the concept of an **electric field.** A charged particle produces an electric field in the space around it. Another charged particle in that field will experience an electric force. This force is due to the electric field associated with the first charged particle.

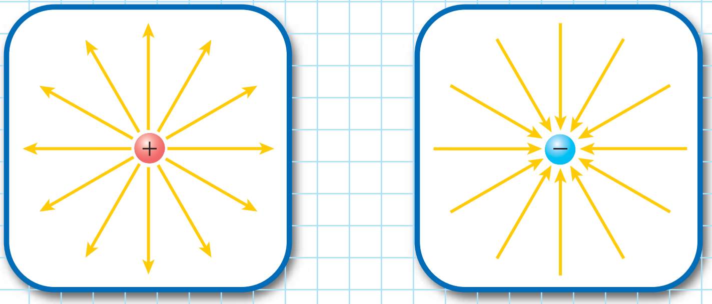
One way to show an electric field is by drawing *electric field lines*. Electric field lines point in the direction of the electric force on a positive charge. Because two positive charges repel one another, the electric field lines around a positive charge point outward, as shown in **Figure 13-6A.** In contrast, the electric field lines around a negative charge point inward, as shown in **Figure 13-6B.** Regardless of the charge, electric field lines never cross one another.

Did You Know?

Electric force and gravitational force both depend on a physical property of objects—charge and mass, respectively—and the distance between the objects. They have the same mathematical form. But gravitational force is attractive, while electric force is both attractive and repulsive. Also, the electric force between two charged particles separated by a given distance is much greater than the gravitational force between the particles.

electric field the region around a charged object in which other charged objects experience an electric force

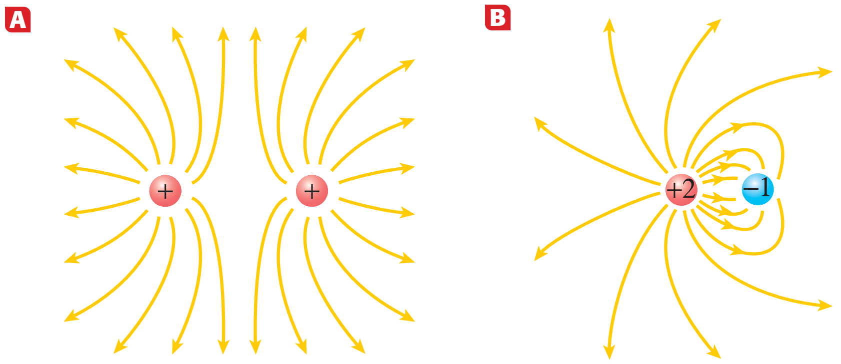
Figure 13-6



A The electric field lines show that a positive charge placed in the electric field due to a positive charge would be pushed away.

B A positive charge placed in the electric field due to a negative charge would be pulled in.

Figure 13-7
(A) The electric field lines for two positive charges show the repulsion between the charges. (B) Half the field lines starting on the positive charge end on the negative charge because the positive charge is twice as great as the negative charge.



You can see from **Figure 13-7** that the electric field between two charges can be represented using these rules. The field lines in **Figure 13-7A** point away from the positive charges, showing that the positive charges repel each other. Field lines show not only the direction of an electric field but also the relative strength due to a given charge. As shown in **Figure 13-7B,** there are twice as many field lines pointing outward from the +2 charge as there are ending on the −1 charge. More lines are drawn for greater charges to indicate greater force.

SECTION 13.1 REVIEW

SUMMARY

- There are two types of electric charge, positive and negative.
- Like charges repel; unlike charges attract.
- The electric force between two charged objects is proportional to the product of the charges and inversely proportional to the distance between them squared.
- Electric force acts through electric fields.
- Electric fields surround charged objects. Any charged object that enters a region with an electric field experiences an electric force.

CHECK YOUR UNDERSTANDING

1. Identify the electric charge of each of the following atomic particles: a proton, a neutron, and an electron.

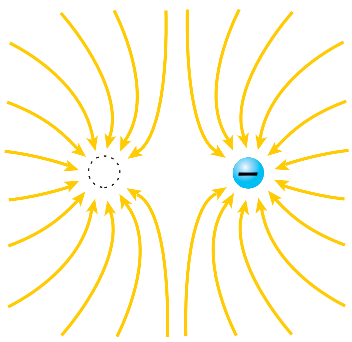
2. Describe the interaction between two like charges.

3. Diagram what will happen if a positively charged rod is brought near the following objects:
a. a metal washer **b.** a plastic disk

4. Categorize the following as conductors or insulators:
a. copper wire
b. rubber tubing
c. your body when your skin is wet
d. a plastic comb

5. Explain how the electric force between two positive charges changes if
a. the distance between the charges is tripled.
b. the amount of one charge is doubled.

6. Critical Thinking What missing electric charge would produce the electric field shown at right?



Back

13.2 Current

OBJECTIVES

- Describe how batteries are sources of voltage.
- Explain how a potential difference produces a current in a conductor.
- Define *resistance.*
- Calculate the resistance, current, or voltage, given the other two quantities.
- Distinguish between conductors, superconductors, semiconductors, and insulators.

KEY TERMS

electrical potential energy
potential difference
cell
current
resistance

When you wake up in the morning, you reach up and turn on the light switch. The light bulb is powered by moving charges. How do charges move through a light bulb? And what causes the charges to move?

PHYSICAL SCIENCE INTERACTIVE TUTOR

Disc One, Module 8:
Batteries and Cells
Use the Interactive Tutor to learn more about these topics.

Voltage and Current

Gravitational potential energy depends on the relative position of the ball, as shown in **Figure 13-8A.** A ball rolling downhill moves from a position of higher gravitational potential energy to one of lower gravitational potential energy. An electric charge also has potential energy—**electrical potential energy**—that depends on its position in an electric field.

electrical potential energy potential energy of a charged object due to its position in an electric field

Just as a ball will roll downhill, a negative charge will move away from another negative charge. This is because of the first negative charge's electric field. The electrical potential energy of the moving charge decreases, as shown in **Figure 13-8B,** because the electric field does work on the charge.

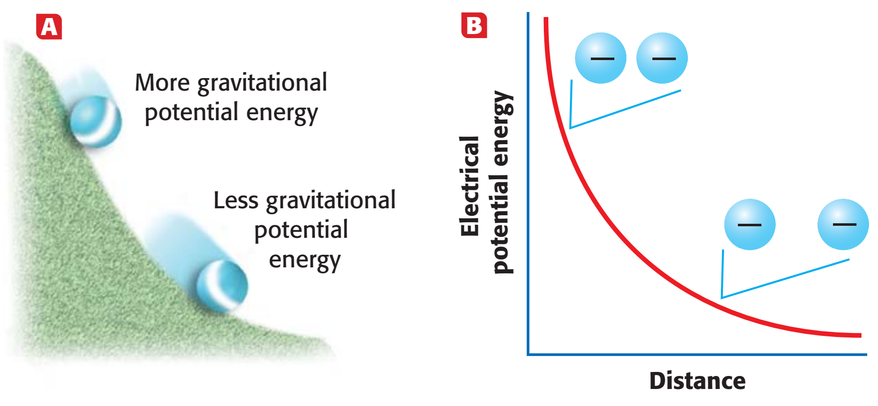


Figure 13-8
(A) The gravitational potential energy of a ball decreases as it rolls downhill. (B) The electrical potential energy between two negative charges decreases as the distance between them increases.

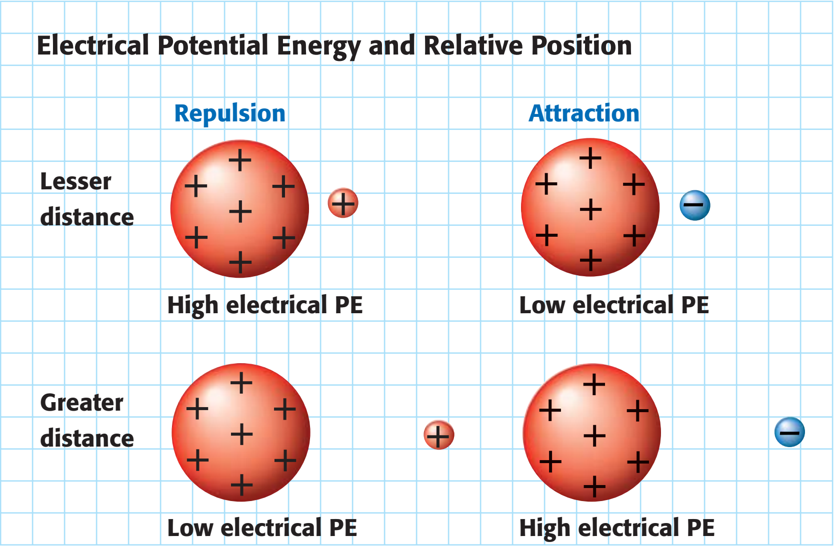


Figure 13-9
The electrical potential energy of a charge depends on its position in an electric field.

You can do work on a ball to move it uphill. This will increase the ball's gravitational potential energy. In the same way, a force can push a charge in the opposite direction of the electric force. This increases the electrical potential energy associated with the charge's relative position. **Figure 13-9** shows how the electrical potential energy depends on the distance between two charged objects for both an attractive and a repulsive electric force.

Potential difference is measured in volts

When studying electricity, it is more practical to consider the **potential difference** than the electrical potential energy. Potential difference is the change in the electrical potential energy of a charged particle divided by its charge. This change occurs as a charge moves from one place to another in an electric field.

The SI unit for potential difference is the *volt,* V, which is equivalent to one joule per coulomb (1 J/C). For this reason, potential difference is often called *voltage.*

potential difference the change in the electrical potential energy per unit charge

cell a device that is a source of electric current because of a potential difference, or voltage, between the terminals

There is a voltage across the terminals of a battery

The voltage across the two *terminals* of a battery can range from about 1.5 V for a small battery to about 12 V for a car battery, as shown in **Figure 13-10.** Most common batteries are an electric **cell**—or a combination of connected electric cells—that convert chemical energy into electrical energy. One terminal is positive, and the other is negative. A summary of various types of electric cells is given in **Table 13-1.**

Electrochemical cells contain an *electrolyte,* a solution that conducts electricity, and two *electrodes,* each a different conducting material. These cells can be dry cells or wet cells. Dry cells, such as those used in flashlights, contain a paste-like electrolyte. Wet cells, such as those used in almost all car batteries, contain a liquid electrolyte. An average cell has a potential difference of 1.5 V between the positive and negative terminals.

Figure 13-10
For a typical car battery, there is a voltage of 12 V across the negative (black) terminal and the positive (red) terminal.

A voltage sets charges in motion

When a flashlight is switched on, the terminals of the battery are connected through the light bulb. Electrons move through the light bulb from the negative terminal to the positive terminal.

Table 13-1 **Types of Electric Cells**

Electrical cell	Basic principle	Uses
Electrochemical	Electrons are transferred between different metals immersed in an electrolyte.	Common batteries, automobile batteries
Photoelectric and photovoltaic	Electrons are released from a metal when struck by light of sufficient energy.	Artificial satellites, calculators, streetlights
Thermoelectric	Two different metals are joined together, and the junctions are held at different temperatures, causing electrons to flow.	Thermostats for furnaces and ovens
Piezoelectric	Opposite surfaces of certain crystals become electrically charged when under pressure.	Crystal microphones and headsets, computer keypads, record stylus

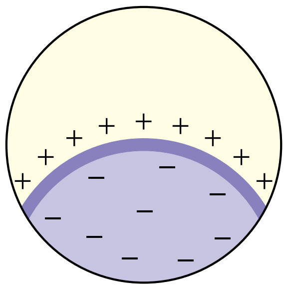
When charges are accelerated by an electric field to move to a position of lower potential energy, an electric **current** is produced. Current is the rate that these charges move through a conductor. The SI unit of current is the *ampere,* A. One ampere, or *amp,* equals 1 C of charge moving past a point in 1 second.

current the rate that electric charges move through a conductor

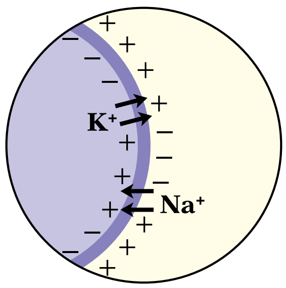
A battery is a *direct current* source because the charges always move from one terminal to the other in the same direction. Current can be made up of positive, negative, or a combination of both positive and negative charges. In metals, moving electrons make up the current. In gases and many chemical solutions, current is the result of both positive and negative charges in motion.

In our bodies, current is mostly positive charge movement. Nerve signals are in the form of a changing voltage across the nerve cell membrane. **Figure 13-11A** shows that a resting cell has more negative charges on the inside than on the outside. **Figure 13-11B** shows how a nerve impulse moves along the cell membrane. As one end of the cell is stimulated, channels nearby in the cell membrane open, allowing Na^+ ions to enter. Later, potassium channels open, and K^+ ions exit the cell, restoring the original voltage across the cell membrane.

Figure 13-11



A A resting nerve cell is more negatively charged than its surroundings.



B As a nerve impulse moves along the cell membrane, the voltage across it changes.

Conventional current is defined as movement of positive charge

A negative charge moving in one direction has the same effect as a positive charge moving in the opposite direction. *Conventional current* is defined as the current made of positive charge that would have the same effect as the actual motion of charge in the material. *In this book, the direction of current will always be given as the direction of positive charge movement that is equivalent to the actual motion of charges in the material.* So the direction of current in a wire is opposite the direction that electrons move in that wire.

Science and the Consumer

Which Is the Best Type of Battery?

"Heavy-duty," "long-lasting alkaline," and "environmentally friendly rechargeable" are some of the labels that manufacturers put on batteries. But how do you know which type to use?

The answer depends on how you will use the battery. Some batteries are used continuously, but others are turned off and on frequently, such as those used in a stereo. Still other batteries must be able to hold a charge without being used, such as those used in smoke detectors and flashlights.

Heavy-duty Batteries Are Inexpensive

In terms of price, a heavy-duty battery typically costs the least but lasts only about 30 percent as long as an alkaline battery. This makes heavy-duty batteries impractical for most uses and an unnecessary source of landfill clutter.

Regular Alkaline Batteries Are Expensive but Long-lasting

Regular alkaline batteries are more expensive but have longer lives, lasting up to 6 hours with continuous use and up to 18 hours with intermittent use. They hold a full charge for years, making them good for use in flashlights and similar devices. They are less of an environmental problem than they previously were because manufacturers have stopped using mercury in them. However, because they are single-use batteries, they also end up in landfills very quickly.

Rechargeable Batteries Don't Clutter Landfills

Rechargeable batteries are the most expensive to purchase initially. If recycled, however, they are the most economical in the long run and are the most environmentally sound choice. The most common rechargeable cells are either NiCads—containing nickel, Ni, and cadmium, Cd, metals—or alkaline. Either type of rechargeable battery can be recharged hundreds of times. Although rechargeable batteries last only about half as long on one charge as regular alkaline batteries, the energy to recharge them costs pennies. NiCads lose about 1 percent of their stored energy each day they are not used and should therefore never be used in smoke detectors or flashlights. However, rechargeable alkaline batteries retain a charge like regular batteries and can be used in such devices.

Your Choice

1. **Making Decisions** Which type of battery would you use in a portable stereo? Explain your reasoning.
2. **Critical Thinking** Why is it important not to use NiCads in smoke detectors?
3. **Locating Information** Use library resources or the Internet to learn more about batteries used in gasoline-powered and electric cars. Prepare a summary of the types of rechargeable car batteries available.

internetconnect

SCILINKS NSTA

TOPIC: Batteries
GO TO: www.scilinks.org
KEYWORD: HK1134

Back

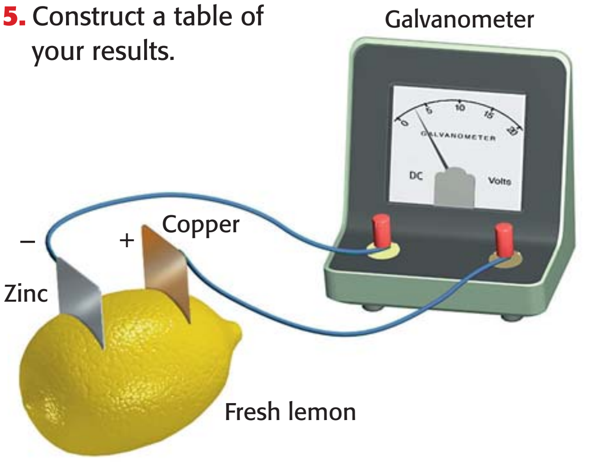
Quick ACTIVITY

Using a Lemon as a Cell

Because lemons are very acidic, their juice can act as an electrolyte. If various metals are inserted into a lemon to act as electrodes, the lemon can be used as an electrochemical cell.

SAFETY CAUTION Handle the wires only where they are insulated.

1. Using a knife, make two parallel cuts 6 cm apart along the middle of a juicy lemon. Insert a copper strip into one of the cuts and a zinc strip the same size into the other.
2. Cut two equal lengths of insulated copper wire. Use wire cutters to remove the insulation from both ends of each wire. Connect one end of each wire to one of the terminals of a galvanometer.
3. Touch the free end of one wire to the copper strip in the lemon. Touch the free end of the other wire to the zinc strip, as shown in the figure at right. Record the galvanometer reading for the zinc-copper cell.
4. Replace the strips of copper and zinc with equally sized strips of different metals. Record the galvanometer readings for each pair of electrodes. Which pair of electrodes resulted in the largest current?
5. Construct a table of your results.



Electrical Resistance

Most electrical appliances you plug into an outlet are designed for the same voltage: 120 V. But light bulbs come in many varieties, from dim 40 W bulbs to bright 100 W bulbs. These bulbs shine differently because they have different amounts of current in them. The difference in current between these bulbs is due to their **resistance.** Resistance is caused by internal friction, which slows the movement of charges through a conducting material. Because it is difficult to measure the internal friction directly, resistance is defined by a relationship between the voltage across a conductor and the current through it.

resistance the ratio of the voltage across a conductor to the current it carries

The resistance of the *filament* of a light bulb, as shown in **Figure 13-12,** determines how bright the bulb is. The filament of a dim 40 W light bulb has a higher resistance than the filament of a bright 100 W light bulb.

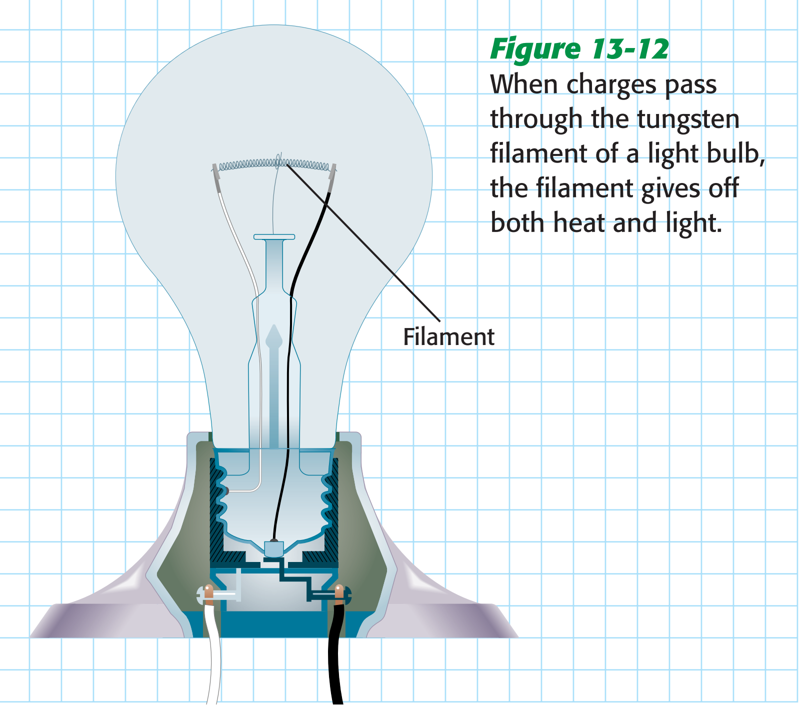


Figure 13-12
When charges pass through the tungsten filament of a light bulb, the filament gives off both heat and light.

Back

Resistance can be calculated from current and voltage

You have probably noticed that electrical devices such as televisions or stereos become warm after they have been on for a while. As moving electrons collide with the atoms of the material, some of their kinetic energy is transferred to the atoms. This energy transfer causes the atoms to vibrate, and the material warms up. In most materials, some of the kinetic energy of electrons is lost as heat.

A conductor's resistance indicates how much the motion of charges within it is resisted because of collisions. Resistance is found by dividing the voltage across the conductor by the current.

Did You Know?

Resistance depends on the material used as well as the material's length, cross-sectional area, and temperature. Longer pieces of a material have greater resistance. Increasing the cross-sectional area of a material decreases its resistance. Lowering the temperature of a material also decreases its resistance.

Resistance Equation

$$resistance = \frac{voltage}{current} \qquad R = \frac{V}{I}$$

The SI unit of resistance is the *ohm,* Ω, which is equal to volts per ampere. If a voltage across a conductor of 1 V produces a current of 1 A, then the resistance of the conductor is 1 Ω.

A *resistor* is a special type of conductor used to control current. Every resistor is designed to have a specific resistance. For example, for any applied voltage, the current in a 10 Ω resistor is half the current in a 5 Ω resistor.

REAL WORLD APPLICATIONS

The Danger of Electric Shock

If you are in contact with the ground, you can receive an electric shock by touching an uninsulated conducting, or "live," wire. An electric shock from such a wire can result in serious burns or even death.

The degree of damage to your body by an electric shock depends on several factors. Large currents are more dangerous than smaller currents. A current of 0.1 A is often fatal. But the amount of time you are exposed to the current also matters. If the current is larger than about 0.01 A, the muscles in the hand touching the wire contract, and you may be unable to let go of the wire. In this case, the charges will continue moving through your body and can cause great damage, especially if the charges pass through a vital organ, such as the heart.

Current (A)	Effect
0.001	Slight tingle
0.005	Pain
0.010	Muscle spasms
0.015	Loss of muscle control
0.070	Probably fatal (if contact is more than 1 second)

Applying Information

1. You can use the definition of *resistance* to calculate the amount of current that would be in a body, given the voltage and resistance. Using the table above as a reference, determine the effect of touching the terminals of a 24 V battery. Assume that your body is dry and has a resistance of 100 000 Ω.
2. If your skin is moist, your body's resistance is only about 1000 Ω. How would touching the terminals of a 24 V battery affect your body if your skin is moist?

Back

Math Skills

Resistance The headlights of a typical car are powered by a 12 V battery. What is the resistance of the headlights if they draw 3.0 A of current when turned on?

1 List the given and unknown values.

Given: *current,* $I = 3.0$ A

voltage, $V = 12$ V

Unknown: *resistance,* $R = ?\ \Omega$

2 Write the equation for resistance.

$$resistance = \frac{voltage}{current} \qquad R = \frac{V}{I}$$

3 Insert the known values into the equation, and solve.

$$R = \frac{V}{I} = \frac{12\ V}{3.0\ A}$$

$$R = 4.0\ \Omega$$

Practice

Resistance

1. Find the resistance of a portable lantern that uses a 24 V power supply and draws a current of 0.80 A.
2. The current in a resistor is 0.50 A when connected across a voltage of 120 V. What is its resistance?
3. The current in a handheld video game is 0.50 A. If the resistance of the game's circuitry is 12 Ω, what is the voltage produced by the battery?
4. A 1.5 V battery is connected to a small light bulb with a resistance of 3.5 Ω. What is the current in the bulb?

Practice HINT

- When a problem requires you to calculate the resistance of an object, you can use the resistance equation as shown on the previous page.
- The resistance equation can also be rearranged to isolate voltage on the left in the following way:

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

  Multiply both sides by I.

  $$IR = \frac{VI}{I}$$

  $$V = IR$$

  You will need this version of the equation for Practice Problem 3.
- For Practice Problem 4, you will need to rearrange the equation to isolate current on the left.

Conductors have low resistances

Whether or not charges will move in a material depends partly on how tightly electrons are held in the atoms of the material. A good conductor is any material in which electrons can flow easily under the influence of an electric field. Metals, like the copper found in wires, are some of the best conductors because electrons can move freely throughout them. Certain metals, conducting alloys, or carbon are used in resistors.

When you flip the switch on a flashlight, the light seems to come on immediately. But the electrons don't travel that rapidly. The electric field is directed through the conductor at almost the speed of light when a voltage source is connected to the conductor. Electrons everywhere throughout the conductor simultaneously experience a force due to the electric field and move in the opposite direction of the field lines. This is why the light comes on so quickly in a flashlight.

Back

Some materials become superconductors below a certain temperature

Certain metals and compounds have zero resistance when their temperature falls below a certain temperature called the *critical temperature.* These types of materials are called *superconductors.* The critical temperature varies among materials, from less than −272°C (−458°F) to as high as −123°C (−189°F).

Metals such as niobium, tin, and mercury and some metallic compounds containing barium, copper, and oxygen become superconductors below their respective critical temperatures. Superconductors have been used in electrical devices such as filters, powerful magnets, and Maglev high-speed express trains.

Insulators have high resistance

Insulators have high resistance to charge movement. So insulating materials are used to prevent electric current from leaking. For example, plastic coating around the copper wire of an electric cord keeps the current from escaping into the floor or your body.

Sometimes it is important to provide a pathway for current to leave a charged object. So a conducting wire is run between the charged object and the ground, thereby *grounding* the object. Grounding is an important part of electrical safety.

Inquiry Lab

How can materials be classified by resistance?

Materials

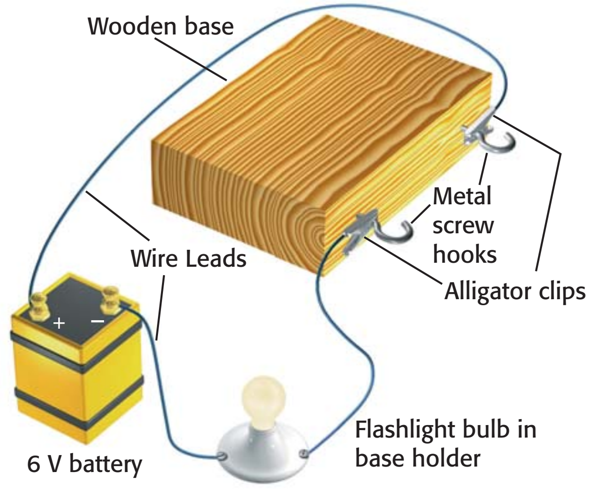
- ✔ *6 V battery*
- ✔ *flashlight bulb in base holder*
- ✔ *2 wire leads with alligator clips*
- ✔ *2 metal hooks*
- ✔ *block of wood*
- ✔ *glass stirring rod*
- ✔ *iron nail*
- ✔ *wooden dowel*
- ✔ *copper wire*
- ✔ *piece of chalk*
- ✔ *strip of cardboard*
- ✔ *plastic utensil*
- ✔ *aluminum nail*
- ✔ *brass key*
- ✔ *strip of cork*

Procedure

1. Construct a conductivity tester, as shown in the diagram.
2. Test the conductivity of various materials by laying the objects one at a time across the hooks of the conductivity tester.

Analysis

1. What happens to the conductivity tester if a material is a good conductor?
2. Which materials were good conductors?
3. Which materials were poor conductors?
4. Explain the results in terms of resistance.



Back

Many electrical sockets are wired with three connections: two current-carrying wires and the ground wire. If there is any charge buildup, or if the live wire contacts an appliance, the ground wire conducts the charge to the Earth. The excess charge can spread over the planet safely.

Semiconductors are intermediate to conductors and insulators

Semiconductors belong to a third class of materials with electrical properties between those of insulators and conductors. In their pure state, semiconductors are insulators. The controlled addition of specific atoms of other materials as impurities dramatically increases a semiconductor's ability to conduct electric charge. Silicon and germanium are two common semiconductors. Complex electrical devices, like the computer board shown in **Figure 13-13**, are made of conductors, insulators, and semiconductors.

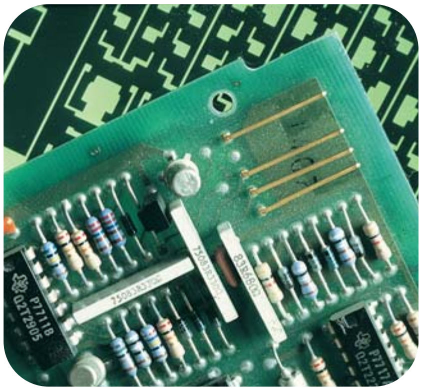


Figure 13-13
Most electrical devices contain conductors, insulators, and semiconductors.

SECTION 13.2 REVIEW

SUMMARY

- A charged object has electrical potential energy due to its position in an electric field.
- Potential difference, or voltage, is the difference in electrical potential energy per unit charge.
- A voltage causes charges to move, producing a current.
- Current is the rate of charge movement.
- Electrical resistance can be calculated by dividing voltage by current.
- Conductors are materials in which electrons flow easily.
- Superconductors have no resistance below their critical temperature.
- Insulators are materials with high resistance.

CHECK YOUR UNDERSTANDING

1. **Identify** which of the following could produce current:
   a. a wire connected across a battery's terminals
   b. two electrodes in a solution of positive and negative ions
   c. a salt crystal, whose ions cannot move
   d. a sugar-water mixture
2. **Predict** which way charges are likely to move between two positions of different electrical potential energy, one high and one low.
   a. from low to high
   b. from high to low
   c. back and forth between high and low
3. **State** the quantities needed to calculate an object's resistance.
4. **Explain** the function of insulation around a wire.
5. **Describe** the motion of charges through a flashlight, from one terminal of a battery to the other.
6. **Classify** the following materials as conductors or insulators: wood, paper clip, glass, air, paper, plastic, steel nail, water, aluminum can.

Math Skills

7. If the current in a certain resistor is 6.2 A and the voltage across the resistor is 110 V, what is its resistance?
8. If the voltage across a flashlight bulb is 3 V and the bulb's resistance is 6 Ω, what is the current through the bulb?

Back

Circuits

KEY TERMS
electric circuit
schematic diagram
series
parallel
electrical energy
fuse
circuit breaker

OBJECTIVES

- Use schematic diagrams to represent circuits.
- Distinguish between series and parallel circuits.
- Calculate electric power using voltage and current.
- Explain how fuses and circuit breakers are used to prevent circuit overload.

Disc Two, Module 16:
Electrical Circuits
Use the Interactive Tutor to learn more about this topic.

electric circuit an electrical device connected so that it provides one or more complete paths for the movement of charges

Think about how you would get the bulb shown in **Figure 13-14** to light up. Would the bulb light if the bulb were not fully screwed into the socket? How about if one of the clips were removed from the battery?

What Are Circuits?

When a wire connects the terminals of the battery to the light bulb, as shown in **Figure 13-14,** charges that built up on one terminal of the battery have a path to follow to reach the opposite charges on the other terminal. Because there are charges moving uniformly, a current exists. This current causes the filament inside the light bulb to give off heat and light.

An electric circuit is a path through which charges can be conducted

Together, the bulb, battery, and wires form an **electric circuit.** In the circuit shown in **Figure 13-14,** the path from one battery terminal to the other is complete. Because of the voltage of the battery, electrons move through the wires and bulb from the negative terminal to the positive terminal. Then the battery adds energy to the charges as they move within the battery from the positive terminal back to the negative one.

In other words, there is a closed-loop path for electrons to follow. The conducting path produced when the light bulb is connected across the battery's terminals is called a *closed circuit.* Without a complete path, there is no charge flow and therefore no current. This is called an *open circuit.*

The inside of the battery is part of the closed path of current through the circuit. The voltage source, whether a battery or an outlet, is always part of the conducting path of a closed circuit.

Figure 13-14
When this battery is connected to a light bulb, the voltage across the battery generates a current that lights the bulb.

Back

If a device called a *switch* is added to the circuit, as shown in **Figure 13-15,** you can use the switch to open and close the circuit. You have used a switch many times. The switches on your wall at home are used to turn lights on and off. Although they look different from the switch in **Figure 13-15,** their function is the same. When you flip a switch at home, you either close or open the circuit to turn a light on or off.

The switch shown in **Figure 13-15** is called a knife switch. The metal bar is a conductor. When the bar is touching both sides of the switch, as shown in **Figure 13-15,** the circuit is closed. Electrons can move through the bar to reach the other side of the switch and light the bulb. If the metal bar on the switch is lifted, the circuit is open. Then there is no current, and the bulb does not glow.

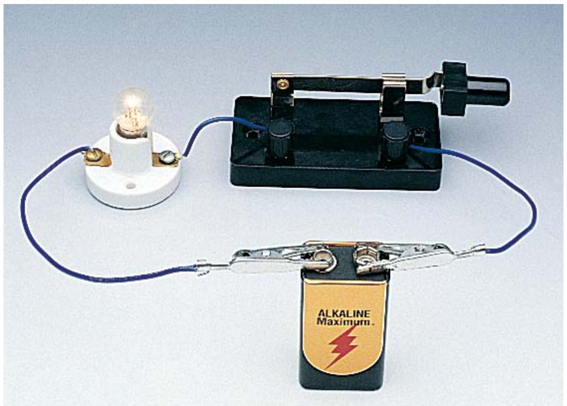


Figure 13-15
When added to the circuit, a switch can be used to open and close the circuit.

Schematic diagrams are used to represent circuits

Suppose you wanted to describe to someone the contents and connections in the photo of the light bulb and battery in **Figure 13-15.** How might you draw each element? Could you use the same representations of the elements to draw a bigger circuit, such as a string of lights?

A diagram that depicts the construction of an electrical circuit or apparatus is called a **schematic diagram. Figure 13-16** shows how the battery and light bulb can be drawn as a schematic diagram. The symbols that are used in this figure can be used to describe any other circuit with a battery and one or more bulbs. All electrical devices, from toasters to computers, can be described using schematic diagrams. Because schematic diagrams use standard symbols, they can be read by people all over the world.

internetconnect

SCI LINKS NSTA

TOPIC: Electric circuits
GO TO: www.scilinks.org
KEYWORD: HK1135

schematic diagram
a graphic representation of an electric circuit or apparatus, with standard symbols for the electrical devices

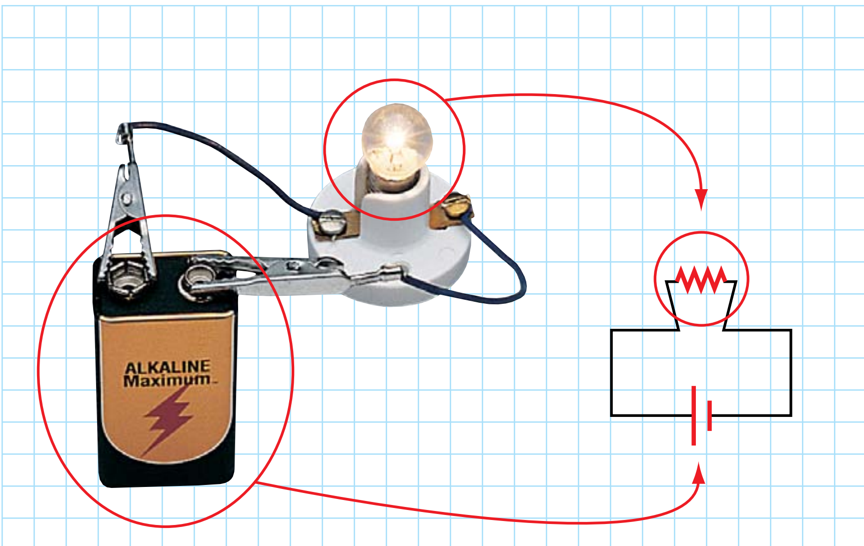
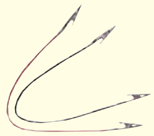
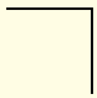
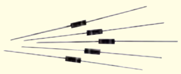
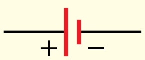
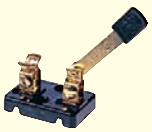
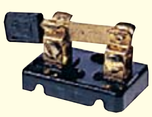


Figure 13-16
The connections between the light bulb and battery can be represented by symbols. This type of illustration is called a schematic diagram.

As shown in **Table 13-2,** each element used in a piece of electrical equipment is represented by a symbol that reflects the element's construction or function. For example, the schematic-diagram symbol that represents an open switch resembles the open-knife switch shown in the corresponding photograph. Any circuit can be drawn using a combination of these and other, more-complex schematic diagram symbols.

Table 13-2 **Schematic Diagram Symbols**

Component	Symbol used in this book	Explanation
Wire or conductor 		Wires that connect elements are conductors.
Resistor 		Resistors are shown as wires with multiple bends, indicating resistance to a straight path.
Bulb or lamp 		The winding of the filament indirectly indicates that the light bulb is a resistor, something that impedes the movement of electrons or the flow of charge.
Battery or other direct current source 		The difference in line height indicates a voltage between positive and negative terminals of the battery. The taller line represents the positive terminal of the battery.
Switch  Open  Closed	 Open  Closed	The small circles indicate the two places where the switch makes contact with the wires. Most switches work by breaking only one of the contacts, not both.

Back

Series and Parallel Circuits

Section 13.2 showed that the current in a circuit depends on voltage and the resistance of the device in the circuit. What happens when there are two or more devices connected to a battery?

Series circuits have a single path for current

When appliances or other devices are connected in a **series** circuit, as shown in **Figure 13-17A,** they form a single pathway for charges to flow. Charges cannot build up or disappear at a point in a circuit. For this reason, the amount of charge that enters one device in a given time interval equals the amount of charge that exits that device in the same amount of time. Because there is only one path for a charge to follow when devices are connected in series, the current in each device is the same. Even though the current in each device is the same, the resistances may be different. Therefore, the voltage across each device in a series circuit can be different.

If one element along the path in a series circuit is removed, the circuit will not work. For example, if either of the light bulbs in **Figure 13-17A** were removed, the other one would not glow. The series circuit would be open. Several kinds of breaks may interrupt a series circuit. The opening of a switch, the burning out of a light bulb, a cut wire, or any other interruption can cause the whole circuit to fail.

Parallel circuits have multiple paths for current

When devices are connected in **parallel,** rather than in series, the voltage across each device is the same. The current in each device does not have to be the same. Instead, the sum of the currents in all of the devices equals the total current. A simple parallel circuit is shown in **Figure 13-17B.** The two lights are connected to the same points. The electrons leaving one end of the battery can pass through either bulb before returning to the other terminal. If one bulb has less resistance, more charge moves through that bulb because the bulb offers less opposition to the movement of charges.

Even if one of the bulbs in the circuit shown in **Figure 13-17B** were removed, charges would still move through the other loop. Thus, a break in any one path in a parallel circuit does not interrupt the flow of electric charge in the other paths.

Quick ACTIVITY

Series and Parallel Circuits

1. Connect two flashlight bulbs, a battery, wires, and a switch so that both bulbs light up.
2. Make a diagram of your circuit. Is it a series or a parallel circuit?
3. Now make the other type of circuit. Compare the brightness of the bulbs in the two types of circuits.

series describes a circuit or portion of a circuit that provides a single conducting path

parallel describes components in a circuit that are connected across common points, providing two or more separate conducting paths

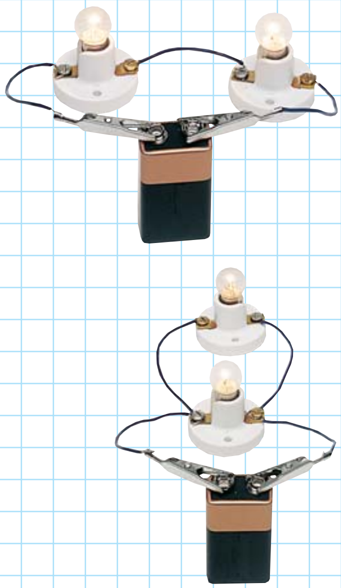


Figure 13-17

A When bulbs are connected in series, charges must pass through both light bulbs to complete the circuit.

B When devices are connected in parallel, charges have more than one path to follow. The circuit can be complete even if one light bulb burns out.

Back

Electric Power and Electrical Energy

electrical energy the energy associated with electrical charges, whether moving or at rest

Many of the devices you use on a daily basis, such as the toaster shown in **Figure 13-18,** require **electrical energy** to run. The energy for these devices may come from a battery or from a power plant miles away.

Electric power is the rate at which electrical energy is used in a circuit

When a charge moves in a circuit, it loses energy. This energy is transformed into useful work, such as the turning of a motor, and is lost as heat in a circuit. The rate at which electrical work is done is called *electric power.* Electric power is the product of total current (I) in and voltage (V) across a circuit.

Figure 13-18
Household appliances use electrical energy to do useful work. Some of that energy is lost as heat.

Electric Power Equation

$$\text{power} = \text{current} \times \text{voltage}$$
$$P = IV$$

The SI unit for power is the watt (W), as shown in Chapter 9. A watt is equivalent to 1 A × 1 V. Light bulbs are rated in terms of watts. For example, a typical desk lamp uses a 60 W bulb.

If you combine the electric power equation above with the equation $V = IR$, the power lost, or *dissipated,* by a resistor can be calculated.

$$P = I^2R = \frac{V^2}{R}$$

VOCABULARY Skills Tip

The SI unit of power, the watt, *was named after the Scottish inventor James Watt in honor of his important work on steam engines.*

Math Skills

Electric Power When a hair dryer is plugged into a 120 V outlet, it has a 9.1 A current in it. What is the hair dryer's power rating?

1 List the given and unknown values.

Given: *voltage,* $V = 120$ V

current, $I = 9.1$ A

Unknown: *electric power,* $P = ?$ W

2 Write the equation for electric power.

$\text{power} = \text{current} \times \text{voltage}$

$P = IV$

3 Insert the known values into the equation, and solve.

$P = (9.1 \text{ A})(120 \text{ V})$

$P = 1.1 \times 10^3$ W

Back

Practice

Electric Power

1. An electric space heater requires 29 A of 120 V current to adequately warm a room. What is the power rating of the heater?
2. A graphing calculator uses a 6.0 V battery and draws 2.6×10^{-3} A of current. What is the power rating of the calculator?
3. A color television has a power rating of 320 W. How much current is in the television when it is connected across 120 V?
4. The operating voltage for a light bulb is 120 V. The power rating of the bulb is 75 W. Find the current in the bulb.
5. The current in the heating element of an electric iron is 5.0 A. If the iron dissipates 590 W of power, what is the voltage across it?

Practice HINT

- When a problem requires you to calculate power, you can use the power equation as shown on the previous page.
- The electric power equation can also be rearranged to isolate current on the left in the following way:

$$P = IV$$

Divide both sides by V.

$$\frac{P}{V} = \frac{I\cancel{V}}{\cancel{V}}$$

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

You will need this version of the equation for Practice Problems 3 and 4.
- For Practice Problem 5, you will need to rearrange the equation to isolate voltage on the left.

Electric companies measure energy consumed in kilowatt-hours

Power companies charge for energy used in the home, not power. The unit of energy that electric companies use to track consumption of energy is the kilowatt-hour (kW•h). One kilowatt-hour is the energy delivered in 1 hour at the rate of 1 kW. In SI units, 1 kW•h = 3.6×10^6 J.

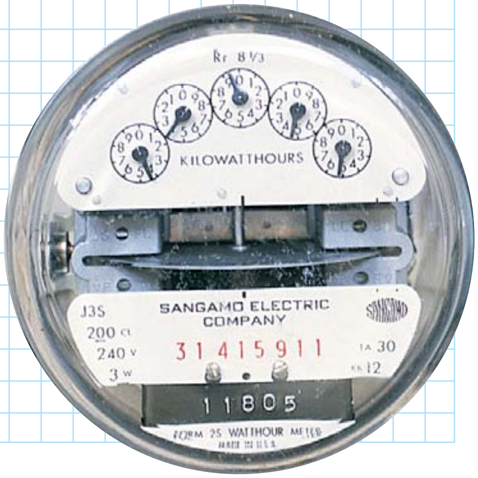
Depending on where you live, the cost of energy ranges from 5 to 20 cents per kilowatt-hour. All homes and businesses have an electric meter, like the one shown in **Figure 13-19.** Electric meters are used by an electric company to determine how much electrical energy is consumed over a certain time interval.

Fuses and Circuit Breakers

When too many appliances, lights, CD players, televisions, and other devices are connected across a 120 V outlet, the overall resistance of the circuit is lowered. That means the electrical wires carry more than a safe level of current. When this happens, the circuit is said to be *overloaded*. The high currents in overloaded circuits can cause fires.

Worn insulation on wires can also be a fire hazard. If a wire's insulation wears down, two wires may touch, creating an alternative pathway for current. This is called a *short circuit*. The decreased resistance greatly increases the current in the circuit. Short circuits can be very dangerous. Grounding appliances reduces the risk of electric shock from a short circuit.

Figure 13-19
An electric meter, like the one shown here, records the amount of energy consumed.



Back

fuse an electrical device containing a metal strip that melts when current in the circuit becomes too great

Fuses melt to prevent circuit overloads

To prevent overloading in circuits, **fuses** are connected in series along the supply path. A fuse is a ribbon of wire with a low melting point. If the current in the line becomes too large, the fuse melts and the circuit is opened.

Fuses "blow out" when the current in the circuit reaches a certain level. For example, a 20 A fuse will melt if the current in the circuit exceeds 20 A. A blown fuse is a sign that a short circuit or a circuit overload may exist somewhere in your home. It is best to find out what made a fuse blow out before replacing it.

circuit breaker a device that protects a circuit from current overloads

Circuit breakers open circuits with high current

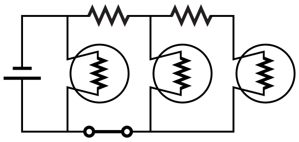
Many homes are equipped with **circuit breakers** instead of fuses. A circuit breaker uses a magnet or *bimetallic strip,* a strip with two different metals welded together, that responds to current overload by opening the circuit. The circuit breaker acts as a switch. As with blown fuses, it is wise to determine why the circuit breaker opened the circuit. Unlike fuses, circuit breakers can be reset by turning the switch back on.

SECTION 13.3 REVIEW

SUMMARY

- An electric circuit is a path along which charges can move.
- In a series circuit, devices are connected along a single pathway. A break anywhere along the path will stop the movement of charges.
- In a parallel circuit, two or more paths are connected to the voltage source. A break along one path will not stop the movement of charges in the other paths.
- Electric power supplied to a circuit or dissipated in a circuit is calculated as the product of the current and voltage.

CHECK YOUR UNDERSTANDING



1. **Identify** the types of elements in the schematic diagram at right and the number of each type.
2. **Describe** the advantage of using a parallel arrangement of decorative lights rather than a series arrangement.
3. **Draw** a schematic diagram with four lights in parallel.
4. **Draw** a schematic diagram of a circuit with two light bulbs in which you could turn off either light and still have a complete circuit. (**Hint:** You will need to use two switches.)
5. **Contrast** how a fuse and a circuit breaker work to prevent overloading in circuits.
6. **Predict** whether a fuse will work successfully if it is connected in parallel with the device it is supposed to protect.

Math Skills

7. When a VCR is connected across a 120 V outlet, the VCR has a 9.5 A current in it. What is the power rating of the VCR?
8. A 40 W light bulb and a 75 W light bulb are in parallel across a 120 V outlet. Which bulb has the greater current?

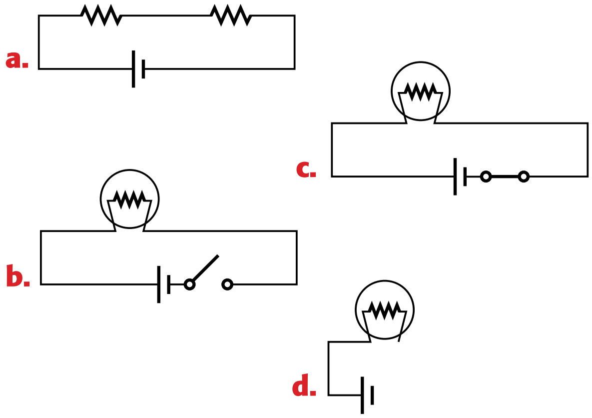
CHAPTER 13 REVIEW

Chapter Highlights

Before you begin, review the summaries of the key ideas of each section, found on pages 436, 445, and 452. The key vocabulary terms are listed on pages 430, 437, and 446.

UNDERSTANDING CONCEPTS

1. Which of the following particles is electrically neutral?
   a. a proton **c.** a hydrogen atom
   b. an electron **d.** a hydrogen ion
2. Which of the following is not an example of charging by friction?
   a. sliding over a plastic-covered car seat
   b. scraping food from a metal bowl with a metal spoon
   c. walking across a woolen carpet
   d. brushing dry hair with a plastic comb
3. The electric force between two objects depends on all of the following except __________.
   a. the distance between the objects
   b. the electric charge of the first object
   c. how the two objects became electrically charged
   d. the electric charge of the second object
4. A positive charge placed in the electric field of a second positive charge will __________.
   a. experience a repulsive force
   b. accelerate away from the second positive charge
   c. have greater electrical potential energy when near the second charge than when farther away
   d. All of the above
5. The __________ is the change in the electrical potential energy of a charged particle per unit charge.
   a. circuit **c.** induction
   b. voltage **d.** power
6. The type of electrical cell in a common battery is __________.
   a. piezoelectric **c.** electrochemical
   b. thermoelectric **d.** photoelectric
7. An electric current does not exist in __________.
   a. a closed circuit **c.** a parallel circuit
   b. a series circuit **d.** an open circuit
8. Which of the following schematic diagrams represent circuits that cannot have current in them as drawn.



9. Which of the following can help prevent a circuit from overloading?
   a. a fuse **c.** a circuit breaker
   b. a switch **d.** both (a) and (c)

Using Vocabulary

10. Explain the energy changes involved when a positive charge moves because of a nearby, negatively charged object. Use the terms *electrical potential energy, work,* and *kinetic energy* in your answer.
11. How do charges move through an insulated wire connected across a battery? Use the terms *potential difference, current, conductor,* and *insulator* in your answer.
12. Contrast the movement of charges in a *series circuit* and in a *parallel circuit*. Use a diagram to aid in your explanation.

CHAPTER 13 REVIEW

BUILDING MATH SKILLS

13. **Electric Force** The electric force is proportional to the product of the charges and inversely proportional to the square of the distance between them. If q_1 and q_2 are the charges on two objects, and d is the distance between them, which of the following represents the electric force, F, between them?

a. $F \propto \frac{q_1q_2}{d}$

b. $F \propto \frac{q_1q_2}{d^2}$

c. $F \propto \frac{d^2}{q_1q_2}$

d. $F \propto \frac{(q_1q_2)^2}{d}$

14. **Resistance** A potential difference of 12 V produces a current of 0.30 A in a piece of copper wire. What is the resistance of the copper wire?
15. **Resistance** What is the voltage across a 75 Ω resistor with 1.6 A of current?
16. **Resistance** A nickel wire with a resistance of 25 Ω is connected across the terminals of a 3.0 V flashlight battery. How much current is in the wire?
17. **Power** A portable cassette player uses 3.0 V (two 1.5 V batteries in series) and has 0.33 A of current. What is its power rating?
18. **Power** Find the current in a 2.4 W flashlight bulb powered by a 1.5 V battery.
19. **Power** A high-voltage transmission line carries 1.0×10^3 A of current. The power transmitted is 7.0×10^8 W. Find the voltage of the transmission line.

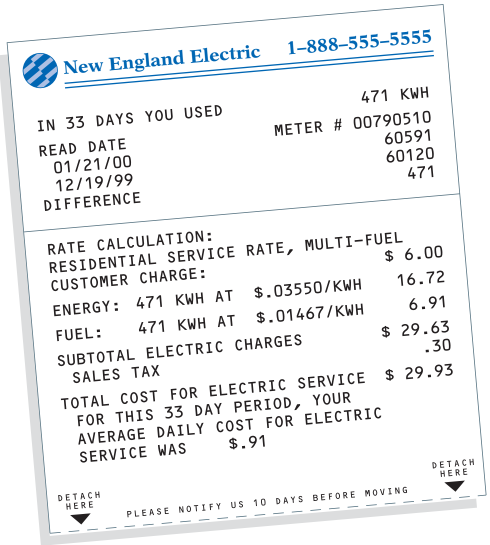
THINKING CRITICALLY

20. **Understanding Systems** Why is charge usually transferred by electrons? Which materials transfer electrons most easily? In what situations can positive charge move?
21. **Applying Knowledge** Why does the electrical resistance of your body decrease if your skin gets wet?
22. **Problem Solving** Humid air is a better electrical conductor because it has a higher water content than dry air. Do you expect shocks from static electricity to be worse as the humidity increases or as it decreases? Explain your answer.
23. **Understanding Systems** The gravitational force is always attractive, while the electric force is both attractive and repulsive. What accounts for this difference?
24. **Designing Systems** How many ways can you connect three light bulbs in a circuit with a battery? Draw a schematic diagram of each circuit.
25. **Applying Knowledge** At a given voltage, which light bulb has the greater resistance, a 200 W light bulb or a 75 W light bulb?

DEVELOPING LIFE/WORK SKILLS

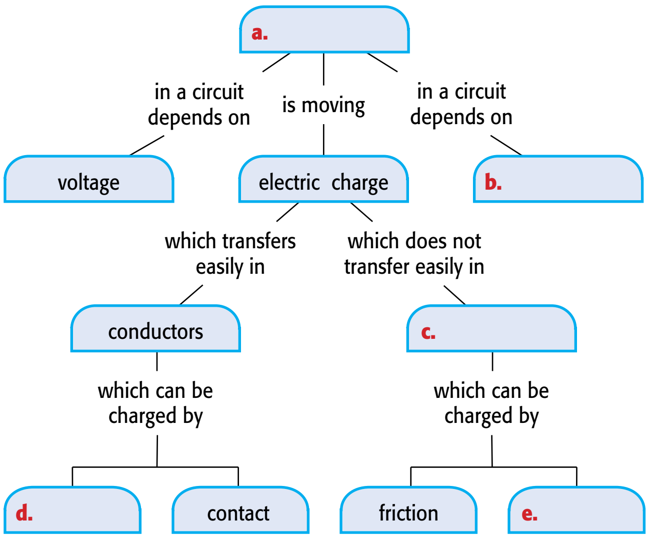
26. **Interpreting and Communicating** COMPUTER SKILL A metal can is placed on a wooden table. If a positively charged ball suspended by a thread is brought close to the can, the ball will swing toward the can, make contact, then move away. Explain why this happens, and predict what will happen to the ball next. Use presentation software or a drawing program to make diagrams showing the charges on the ball and on the can at each phase.
27. **Working Cooperatively** With a small group of classmates, make a chart about electrical safety in the home and outdoors. Use what you have learned in this chapter and information from your local fire department. Include how to prevent electric shock.

28. Allocating Resources Use the electric bill shown below to calculate the average amount of electrical energy used per day and the average cost of fuel to produce the electricity per day.



INTEGRATING CONCEPTS

29. Concept Mapping Copy the unfinished concept map below onto a sheet of paper. Complete the map by writing the correct word or phrase in the lettered boxes.



30. Connection to Social Studies The units of measurement you learned about in this chapter were named after three famous scientists—Alessandro Volta, André-Marie Ampère, and Georg Simon Ohm. Create a presentation about one of these scientists. Research the life, work, discoveries, and contributions of the scientist. The presentation can be in the form of a report, poster, short video, or computer presentation.

31. Connection to Engineering WRITING SKILL Research one of the four types of electrical cells. Write a report describing how it works.

32. Connection to Environmental Science Research how an *electrostatic precipitator* removes smoke and dust particles from the polluting emissions of fuel-burning industries. Find out what industries in your community use a precipitator. What are the advantages and costs of using this device? What alternatives are available? Summarize your findings in a brochure, poster, or chart.

33. Connection to Chemistry Atoms are held together partly because of the electric force between electrons and protons. Chemical bonding is also explained by the attraction between positive and negative particles. Prepare a poster that explains the types of bonding within substances using information from this book and the library. Give examples of common substances that contain these bonds. Describe the relative strengths of the bonds and the types of atoms these bonds form between.

internetconnect

SCILINKS NSTA

TOPIC: Electrostatic precipitators
GO TO: www.scilinks.org
KEYWORD: HK1136

Skill Builder Lab

Introduction

How can you show how the current that flows through an electric circuit depends on voltage and resistance?

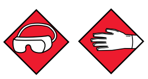
Objectives

- ***Construct*** parallel and series circuits.
- ***Predict*** voltage and current using the resistance law.
- ***Measure*** voltage, current, and resistance.

Materials

dry-cell battery
battery holder
2 resistors
3 connecting wires
masking tape
multimeter

Safety Needs

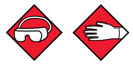


safety goggles
heat-resistant gloves

Constructing Electric Circuits

▶ Preparing for Your Experiment

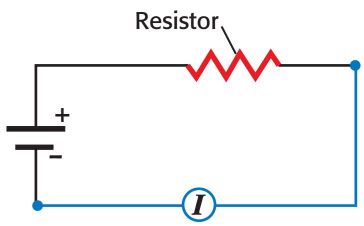
1. In this laboratory exercise, you will use an instrument called a multimeter to measure voltage, current, and resistance. Your teacher will demonstrate how to use the multimeter to make each type of measurement.



2. As you read the steps listed below, refer to the diagrams for help making the measurements. Write down your predictions and measurements in your lab notebook. **SAFETY CAUTION** Handle the wires only where they are insulated.

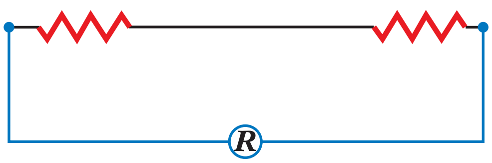
▶ Circuits with a Single Resistor

3. Measure the resistance in ohms of one of the resistors. Write the resistance on a small piece of masking tape, and tape it to the resistor. Repeat for the other resistor.
4. Use the resistance equation to predict the current in amps that will be in a circuit consisting of one of the resistors and one battery. (**Hint:** You must rearrange the equation to solve for current.)
5. Test your prediction by building the circuit. Do the same for the other resistor.

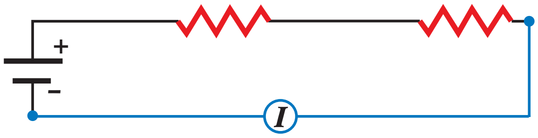


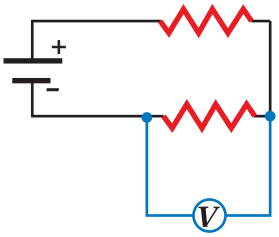
▶ Circuits with Two Resistors in Series

6. Measure the total resistance across both resistors when they are connected in series.



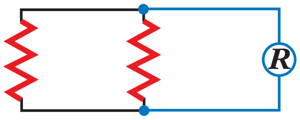
7. Using the total resistance you measured, predict the current that will be in a circuit consisting of one battery and both resistors in series. Test your prediction.



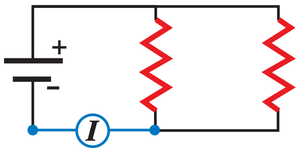


8. Using the current you measured, predict the voltage across each resistor in the circuit you just built. Test your prediction.

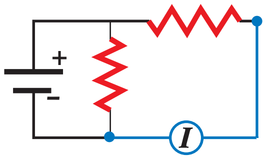
Circuits with Two Resistors in Parallel



9. Measure the total resistance across both resistors when they are connected in parallel.
10. Using the total resistance you measured, predict the total current that will be in an entire circuit consisting of one battery and both resistors in parallel. Test your prediction.



11. Predict the current that will be in each resistor individually in the circuit you just built. Test your prediction.



Analyzing Your Results

1. If you have a circuit consisting of one battery and one resistor, what happens to the current if you double the resistance?
2. What happens to the current if you add a second, identical battery in series with the first battery?
3. What happens to the current if you add a second resistor in parallel with the first resistor?
4. **Reaching Conclusions** Suppose you have a circuit consisting of one battery plus a 10 Ω resistor and a 5 Ω resistor in series. Which resistor will have the greater voltage across it?
5. **Reaching Conclusions** Suppose you have a circuit consisting of one battery plus a 10 Ω resistor and a 5 Ω resistor in parallel. Which resistor will have more current in it?

Defending Your Conclusions

6. Suppose someone tells you that you can make the battery in a circuit last longer by adding more resistors in parallel. Is that correct? Explain your reasoning.

Back

CareerLink

Physicist

Physicists are scientists who are trying to understand the fundamental rules of the universe. Physicists pursue these questions at universities, private corporations, and government agencies. To learn more about physics as a career, read the interview with physicist Robert Martinez, who works at the University of Texas in Austin, Texas.

Robert Martinez uses a microscope that he has developed to identify single molecules.

"I think of our current project a little bit like the nineteenth century explorers did. They didn't know what they would find on the other side of the ridge or the other side of the ocean, but they had to go look."

What kinds of problems are you studying?

We're working on a technique that will allow us to study single molecules. We could look at, say, molecules on the surface of a cell. What we're doing is building a kind of microscope for optical spectroscopy, which is a way to find out the colors of molecules. Studying the colors of molecules can tell us what those molecules are made of.

How does this allow you to identify molecules?

Atoms act as little beams, and the bonds act as little springs. By exciting them with light, we can get them to vibrate and give off different colors of light. It's a little bit like listening to a musical instrument and telling from the overtones that a piano is different from a trumpet or a clarinet.

What facets of your work do you find most interesting?

The thing that I like about what we're doing is that it's very practical, very hands-on. Also, the opportunity exists to explore whole new areas of physics and chemistry that no one has explored before. What we are doing has the promise of giving us new tools—new "eyes"—to look at important problems.

What qualities do you think a physicist needs?

You've got to be innately curious about how the world works, and you've got to think it's understandable and you are capable of understanding it. You've got to be courageous. You've got to be good at math.

Can you remember any experiences that were particularly valuable for you?

When I was growing up, my dad was a pipe fitter for the city of Los Angeles, and I got to be his apprentice. I got a lot of practical experience that way. I think it's important to take the lawn mower engine apart, take the toaster apart—unplug it first—and see how it works.

Which part of your education was most important?

I liked graduate school a great deal. When I started in research, I had an adviser who was very hands off. What I got was the freedom to go as high as I could or to fall on my face. It was a place where I could stretch out and use things I had under my belt but didn't get to use in the classroom. Outside of school, my dad was my best teacher. He was very bright and had a lot of practical experience.

What advice would you give someone interested in physics?

If it interests you at all, stick with it. If you have doubts, try to talk to people who know what physicists do and know about physics training. The number of people with physics training far exceed the number of people who work as physicists. A good fraction of engineering is physics, for instance.

internetconnect

SCILINKS NSTA

TOPIC: Physicist
GO TO: www.scilinks.org
KEYWORD: HK1139

"I think that children are born scientists. It's just a matter of keeping your eyes open—keeping your curiosity alive."

—**Robert Martinez**