Chapter 16
Electricity

Suppose you had a stationary bicycle that was connected to a light bulb so that when you pedaled the bicycle, the energy from the turning wheels lit the bulb. How fast would you have to pedal to generate enough electrical energy to light the bulb? You might be surprised at how fast you would have to pedal to do something that seems so simple. Some science museums have interactive exhibits like this bicycle-powered light bulb to help people see how much energy is needed to accomplish everyday tasks.

What would your life be like without electricity? You can probably name at least a dozen aspects of your morning routine alone that would change if you didn't have electricity. Do you know how electrical circuits work? Do you know what *voltage* and *current* mean? This chapter will give you the opportunity to explore electricity, electrical circuits, and the nature of electrical energy. Electricity can be powerful and dangerous, but when you know the basic facts about how electricity works, you can use electricity safely and with confidence.

Key Questions

- ✔ *What is inside an AA battery, and how does a battery work?*
- ✔ *Why is the shock from a household outlet more dangerous if your skin is wet?*
- ✔ *Are there electrical circuits in the human body? In an electric eel?*

16.1 Charge and Electric Circuits

Like mass, *charge* is a fundamental property of all matter, but one that can easily be overlooked. All matter has electrical properties because the atoms that make up matter contain protons and electrons. In this chapter, you will learn about charge and electric circuits. Many of the devices that we rely on, such as televisions and computers, exist because of electric charge and circuits.

Positive and negative charge

Two kinds of electric charge Virtually all of the matter around you has electric charge because all atoms contain electrons (–) and protons (+). However, unlike mass, electric charge is usually hidden inside atoms. Charge is hidden because atoms are made with equal amounts of positive and negative charges. The forces from **positive** charges are canceled by **negative** charges, the same way that +1 and –1 add up to 0. Because ordinary matter has zero *net* (total) charge, most matter acts as if there is no electric charge at all, and is said to be **electrically neutral**.

Like charges repel and unlike charges attract Whether two charges attract or repel depends on whether they are the same or opposite. A positive and a negative charge will attract each other. Two positive charges will repel each other. Two negative charges will also repel each other. The unit of charge is the **coulomb** (C). The name was chosen in honor of Charles Augustin de Coulomb (1736–1806), a French physicist who performed the first accurate measurements of the force between charges.

Charged objects An object is **charged** when its net charge is *not* zero. If you have ever felt a shock when you have touched a doorknob (Figure 16.1) or removed clothes from a dryer, you have had contact with a charged object. An object with more negative than positive charge has a negative net charge. If it has more positive than negative charge, the object has a positive net charge. The net charge is also sometimes called *excess charge* because a charged object has an excess of either positive or negative charges.

Static electricity and charge A tiny imbalance in either positive or negative charge on an object is the cause of **static electricity**. The static electricity you feel when taking clothes from a dryer or scuffing your socks on a carpet typically results from an excess charge of less than one-millionth of a coulomb.

VOCABULARY

positive, **negative** - the two kinds of electric charge.

electrically neutral - describes an object that has equal amounts of positive and negative charges.

coulomb - the unit for electric charge.

charged - describes an object whose net charge is not zero.

static electricity - caused by a tiny imbalance between positive and negative charge on an object.

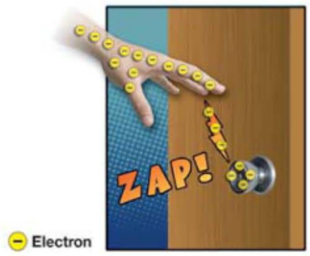


Figure 16.1: *The shock you get from touching a doorknob on a dry day comes from a tiny imbalance of charge.*

Electricity and electric circuits

What is electricity? You just learned that static electricity is caused by a charge imbalance. The word *static* in this case refers to lack of movement. The charge builds up and it might discharge, but it does not always flow in a controlled pathway. The regular electricity that we use on a daily basis, on the other hand, occurs when there is a complete pathway for moving charges. The use of electricity has become so routine that most of us never stop to think about what happens when we switch on a light. Circuits usually consist of wires that carry electricity and devices that use the electricity. **Electricity** refers to the flow of **electric current** in wires, motors, light bulbs, and other objects. Electric current is almost always invisible and comes from the motion of electrons or other charged particles.

Electricity travels in circuits An **electric circuit** is a complete path through which electricity travels. A good example of a circuit is the one in an electric toaster. Bread is toasted by heaters that convert electrical energy to heat. The circuit has a switch that turns on when the lever on the side of the toaster is pushed down. With the switch on, electric current enters through one prong of the plug from the socket in the wall, and goes through the toaster and out the other prong.

Wires are like pipes for electricity Wires in electric circuits are similar in some ways to pipes and hoses that carry water (Figure 16.2). Wires act like pipes for electric current. Current enters the house on the supply wire and leaves on the return wire. The big difference between wires and water pipes is that you can't get electricity to leave a wire the way you can get water to leave a pipe.

Examples of circuits in nature Circuits are not confined to appliances, wires, and devices built by people. The first experience humans had with electricity was in the natural world. Following are some examples of natural circuits.

- The tail of an electric eel makes a circuit when it stuns a fish with a jolt of electricity.
- The Earth makes a gigantic circuit when lightning carries electric current between the clouds and the ground.
- The nerves in your body form an electric circuit that carries messages from your brain to your muscles.

VOCABULARY

electricity - the science of electric charge and current.

electric current - the flow of electric charge.

electric circuit - a complete path through which electric charge flows.

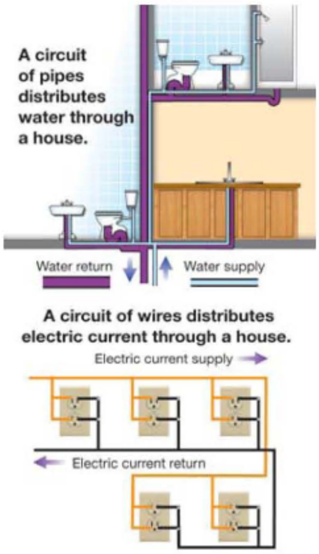
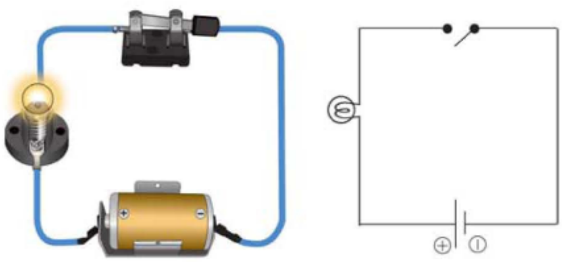


Figure 16.2: *Comparing "circuits" for water and electricity.*

Circuit diagrams and electrical symbols

Circuit diagrams Circuits are made up of wires and electrical parts such as *batteries*, *light bulbs*, *motors*, and *switches*. When designing a circuit, drawings are made to show how the parts are connected. These drawings are called *circuit diagrams*. In a circuit diagram, symbols are used to represent each part of the circuit. Using these *electrical symbols* makes drawing circuits quicker and easier than drawing realistic pictures of each part of the circuit.

Electrical symbols A circuit diagram is a shorthand method of describing a working circuit. The electrical symbols used in circuit diagrams are standard so that anyone familiar with electricity can build the circuit by looking at the diagram. Figure 16.3 shows some common parts of a circuit and their electrical symbols. The picture below shows an actual circuit on the left and its circuit diagram on the right. Can you identify the real parts with their symbols? Note that the switch is open in the circuit diagram, but closed in the actual circuit. Closing the switch completes the circuit so the light bulb lights.



Resistors A **resistor** is an electrical device that uses or controls the energy carried by electric current. In many circuit diagrams, any electrical device that uses energy is shown with a resistor symbol. A light bulb, heating element, speaker, or motor can be drawn with a resistor symbol. Later in this chapter you will learn how resistors are used in electric circuits.

VOCABULARY

resistor - a device that uses energy carried by electric current; resistors are often used to control current in a circuit.

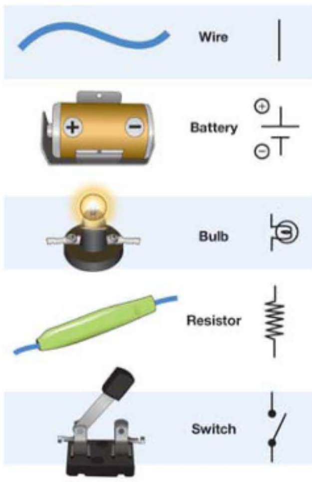


Figure 16.3: *These electrical symbols are used when drawing circuit diagrams.*

Open and closed circuits

Batteries All electric circuits must have a source of energy. Circuits in your home get their energy from power plants that generate electricity. Circuits in flashlights, cell phones, cameras, and portable radios get their energy from batteries. Some calculators have solar cells that convert energy from the Sun or other sources of light into electrical energy. Of all the types of circuits, those with batteries are the easiest to understand. We will focus on battery circuits for now and will eventually learn how circuits in buildings work.

Open and closed circuits We want to be able to turn light bulbs, radios, and other devices used in circuits on and off. One way to turn off a device is to stop the current by "breaking" the circuit. Electric current can only flow when there is a complete and unbroken path from one end of the circuit to the other. A circuit with no breaks is called a **closed circuit**. A light bulb will light only when it is part of a closed circuit. Opening a switch or disconnecting a wire creates a break in the circuit and stops the current. A circuit with any break in it is called an **open circuit** (Figure 16.4).

Switches **Switches** are used to turn electricity on and off. Flipping a switch to the off position creates an open circuit by making a break in the wire. The break stops the current because electricity cannot normally travel through air. Flipping a switch to the on position closes the break and allows the current to flow again, supplying energy to the bulb, radio, or other device.

Breaks in circuits A switch is not the only way to make a break in a circuit. An incandescent light bulb burns out when the thin wire that glows inside it breaks. This creates an open circuit and explains why a burned-out bulb cannot light. Today, incandescent bulbs are being replaced with compact fluorescent light bulbs (CFLs), which use less electrical energy to put out the same amount of light. CFLs work differently than incandescent bulbs. Instead of having a thin wire inside that gets heated, a CFL is a coiled glass tube that contains a gas. When the circuit is closed, electricity passes through the gas-filled tube and causes the atoms in the gas to emit light. Just like incandescent bulbs however, when a CFL bulb does finally quit working, the circuit will be broken and the CFL will need to be replaced.

VOCABULARY

closed circuit - a circuit with no breaks so charge can flow.

open circuit - a circuit with a break so charge cannot flow.

switch - a device that controls the flow of electricity in a circuit.

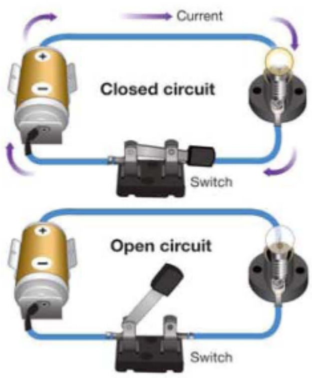
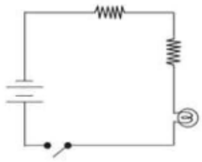


Figure 16.4: *There is current in a closed circuit but not in an open circuit.*

Section 16.1 Review

1. Explain the difference between an electrically charged object and a neutral object. Does a neutral object contain any electric charge at all?
2. If you rub an air-filled balloon on your hair, you can make it stick to a wall. When the balloon and your hair are rubbed together, electrons are transferred from your hair to the balloon.
    a. Is the net charge on the balloon after it is rubbed on your hair positive, negative, or zero?
    b. What do you think happens to the atoms near a wall's surface when the charged balloon is brought near the wall? (Hint: The balloon will stick to the wall.)
    c. What happens when you try to stick a charged balloon to a metal object, such as a doorknob? Try it or do some research to find the answer and explain. Don't forget to include website and/or book citations.
3. How are electric circuits and systems for carrying water in buildings similar?
4. Give one example of a circuit found in nature and one example of a fabricated circuit.
5. What is the difference between an open circuit and a closed circuit?
6. How does a resistor function in a circuit? Give an example.
7. Use the circuit diagram at the right to answer the following questions.



    a. How many bulbs are there in this circuit?
    b. How many batteries?
    c. How many resistors?
    d. How many switches?
    e. Is this circuit open or closed? Justify your answer.
8. When you turn a light switch to the on position, does this open or close the circuit? Explain.

SCIENCE FACT

Lightning and Charged Particles

Lightning is caused by a giant buildup of static charge. Before a lightning strike, particles in a cloud collide, and charges are transferred from one particle to another. The forces of gravity and wind cause the different particles to separate. Positively charged particles accumulate near the top of the cloud and negatively charged particles fall toward the bottom. These negatively charged cloud particles repel negative charges in the ground, causing the ground to become positively charged. The negative charges in the cloud are attracted to the positively charged ground. The cloud, air, and ground can act like a giant circuit. All the accumulated negative charges flow from the cloud to the ground, heating the air along the path (to as much as 20,000°C) so that the air glows like a bright streak of light.