The photos on this page show both old windmills, which produce mechanical power, and new wind turbines, which produce electrical power. Which pictures show windmills? Which show turbines? How is (or was) the power of each used?

CHAPTER 11

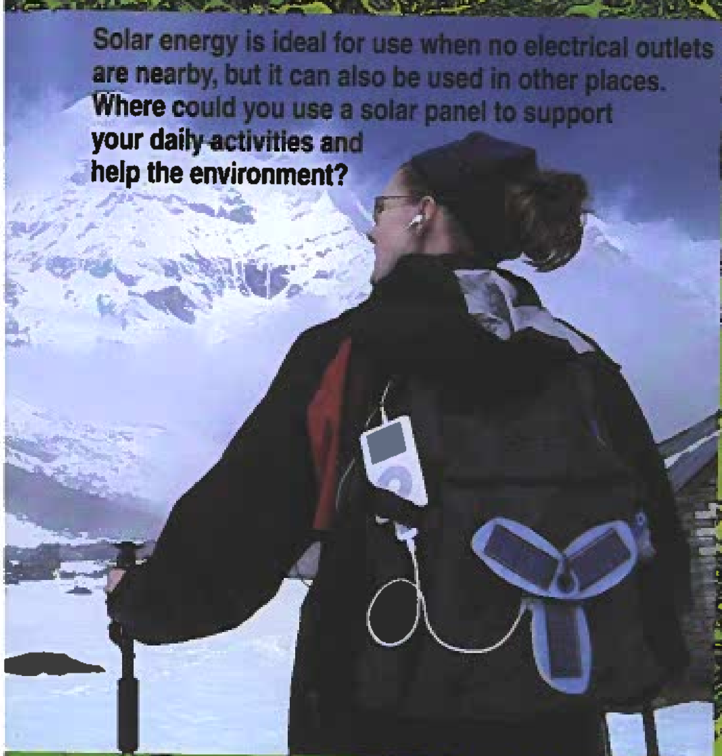
Electricity and Magnetism

Better by Design

Christopher Horner designed the Solio™ solar charger

Using a solar panel allows you to generate your own free, clean electricity directly from the sun.

Christopher Horner and his design team want you to capture the sun's energy and convert it into electricity to power your portable electronics. When opened, a Solio hybrid charger captures light from the sun. When sunlight hits the solar cells, it creates an electric current. This current can either be used directly or stored in its battery. The stronger the sunlight, the more electricity is generated. According to Chris, using a solar-powered Solio is 100 times better for the environment than using a wall charger.



Solar energy is ideal for use when no electrical outlets are nearby, but it can also be used in other places. Where could you use a solar panel to support your daily activities and help the environment?

"We must make renewable energy tangible to the consumer who wants power on the go."

Reading Target

Preview and Prediction

Before you read this chapter, glance through it and read only the heads of each section. Based on this information, try to guess, or predict, what the chapter is about. Use the Reading Target graphic organizer at the end of the chapter to record your predictions.

Key Terms

alternating current (AC)
amperage
anode
battery
cathode
cell
circuit
commutator
conductor
cycle
direct current (DC)
distribution lines
dry cell
electric current
electrode
electrolyte
electromagnetism
electromotive force (EMF)
electron theory
energy density
frequency
generating station
generator
magnetism
primary cell
rotor
secondary cell
stator
step-down transformer
step-up transformer
transmission lines
voltage
voltaic cell

Objectives

After reading this chapter, you will be able to:

- Identify the different ways in which electricity can be produced.
- Describe the transmission and distribution of electricity.
- Explain the nature of electricity by referring to the movement of electrons.
- State the laws of magnetism.
- Explain the concept of electromagnetism.
- Describe how an electric motor operates.
- Explain the difference between cells and batteries.

Useful Web sites:
www.solio.com/
www.clean-energy-ideas.com/solar_panels.html
www.solarpanelinfo.com/

Imagine your town or city without electricity. It can happen. At approximately 4:15 in the afternoon in August 2003, the lives of 50 million people were suddenly interrupted. The power outage included 40 million people in eight states (New York, New Jersey, Vermont, Michigan, Ohio, Pennsylvania, Connecticut, and Massachusetts) and 10 million people in the Canadian province of Ontario. During the outage, 265 power plants shut down, including 22 nuclear power plants.

- Water systems in several cities lost pressure, forcing four million customers in the Detroit area to boil their water for four days.
- Passenger screening at affected airports was stopped, forcing the airports to shut down.
- Some television stations were knocked out of service.
- In New York City, 40,000 police and the entire fire department were on duty to maintain order.
- Commuters were stranded in New York City. Some found lodging, but many were forced to sleep in parks.
- A large number of factories closed in the affected area. Others outside the area were forced to close because of supply problems.
- Buildings became hot because air conditioning no longer functioned.
- Most of the interstate rail transport in the northeast corridor was interrupted.

In February 2004, a task force released a report explaining the main cause of the blackout: the failure to trim trees in parts of Ohio. High-voltage power lines shorted when they came into contact with overgrown trees. A domino effect resulted in the eventual shutdown of more than 100 power plants.

In our daily lives, we take electricity for granted. To most people in the United States, it is merely something that is always available. Only when it is gone do we realize how we depend on it. See **Figure 11-1**.

Figure 11-1. We depend on electrical energy more than we realize. How would a blackout this evening affect you?

Generating Electricity

The electrical energy supplied to your home comes from a generating station. A *generating station* uses energy from a source of power to turn turbines, which produce, or generate, electricity. The two principal types of generating stations are hydroelectric and thermal-electric.

Hydroelectric Generating Stations

Hydro is another word for water. Hydroelectric generating stations use the energy of flowing or falling water. The station is located at a waterfall or dam, as shown in **Figure 11-2**. As the water drops to a lower level, its mass spins a turbine. See **Figure 11-3**. A turbine is a finned wheel. When the falling water strikes the fins, the turbine turns rapidly. The turbines are connected to generators. A *generator* is a device that produces an electric current.

Thermal-Electric Generating Stations

Thermal-electric generating stations use steam to drive turbines. A heat source produces the steam. The steam is directed onto the blades of a turbine, spinning it rapidly. As in hydroelectric systems, the turbines drive generators to produce electricity.

Figure 11-2. A dam stores water and provides a powerful flow to drive turbines.

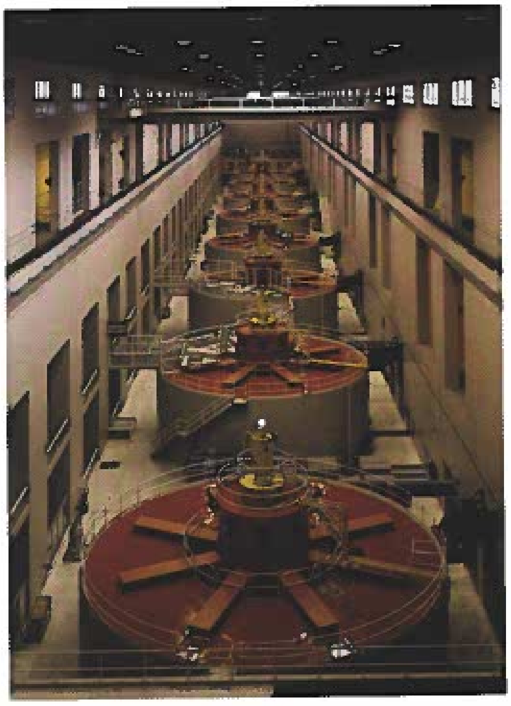


Figure 11-3. The turbine room of a hydroelectric generating station.

Heat for powering thermal-electric turbines comes from one of two sources: fossil fuels or nuclear fission. Refer to Chapter 10 for more information about these energy sources.

The process of burning fossil fuels to generate electricity is shown in Figure 11-4. In a nuclear station, the nuclear reactor does the same job as the furnace in fossil-fuel stations. See Figure 11-5. However, instead of combustion, the energy source used to heat the fluid is nuclear fission. Recall that nuclear fission is the process of splitting atoms. Atoms contain energy that binds them together. When the nucleus of an atom is split, some of the energy that was used to bind the atom together is released as heat. This heat is pumped to the heat exchanger, where it turns water to steam. The steam drives turbines connected to electrical generators. A thick concrete shield stops harmful radioactive substances from escaping.

Hydroelectric generating stations change the potential energy of water behind a dam. As it falls into the turbine, it becomes kinetic energy. Thermal-electric generating stations convert the energy stored in fossil fuels and uranium into kinetic energy. In both cases, the kinetic energy is converted to electrical energy by generators. See Figure 11-6.

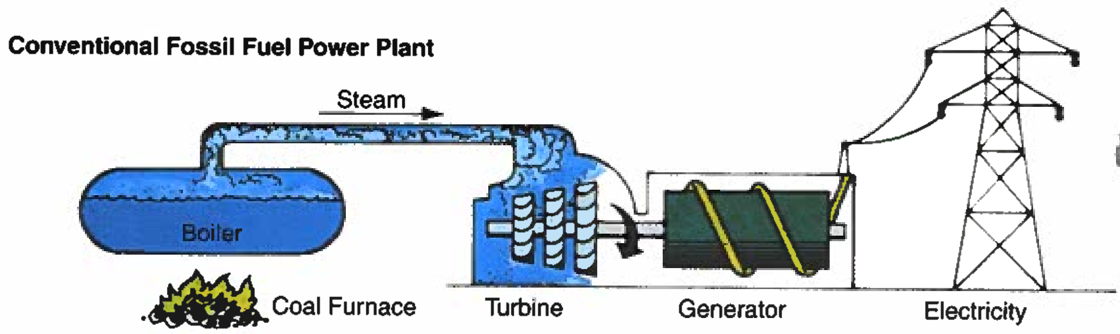


Figure 11-4. The parts of a coal-fired generating system.

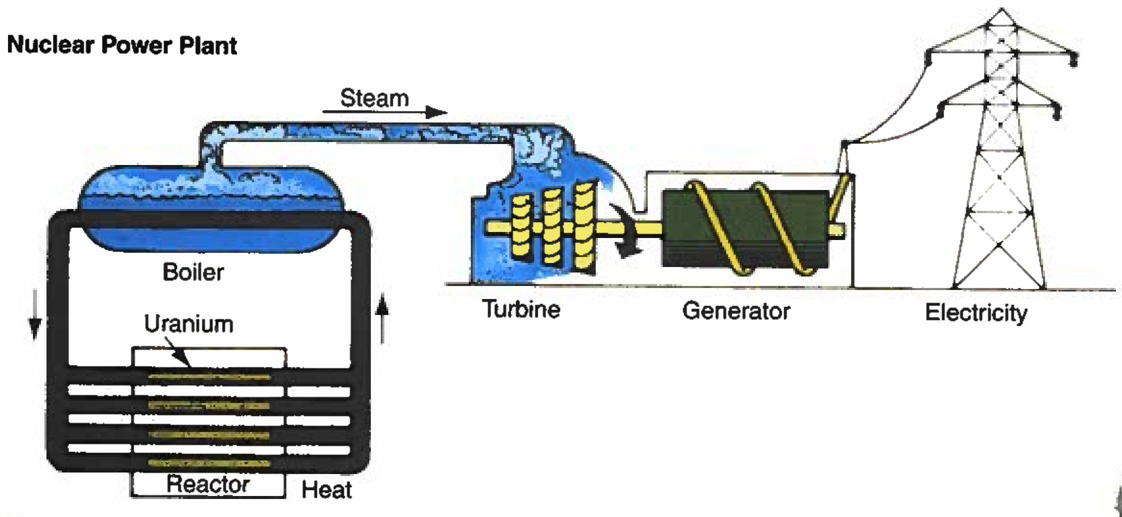


Figure 11-5. Splitting atoms, rather than burning coal, provides the heat in a nuclear power station.

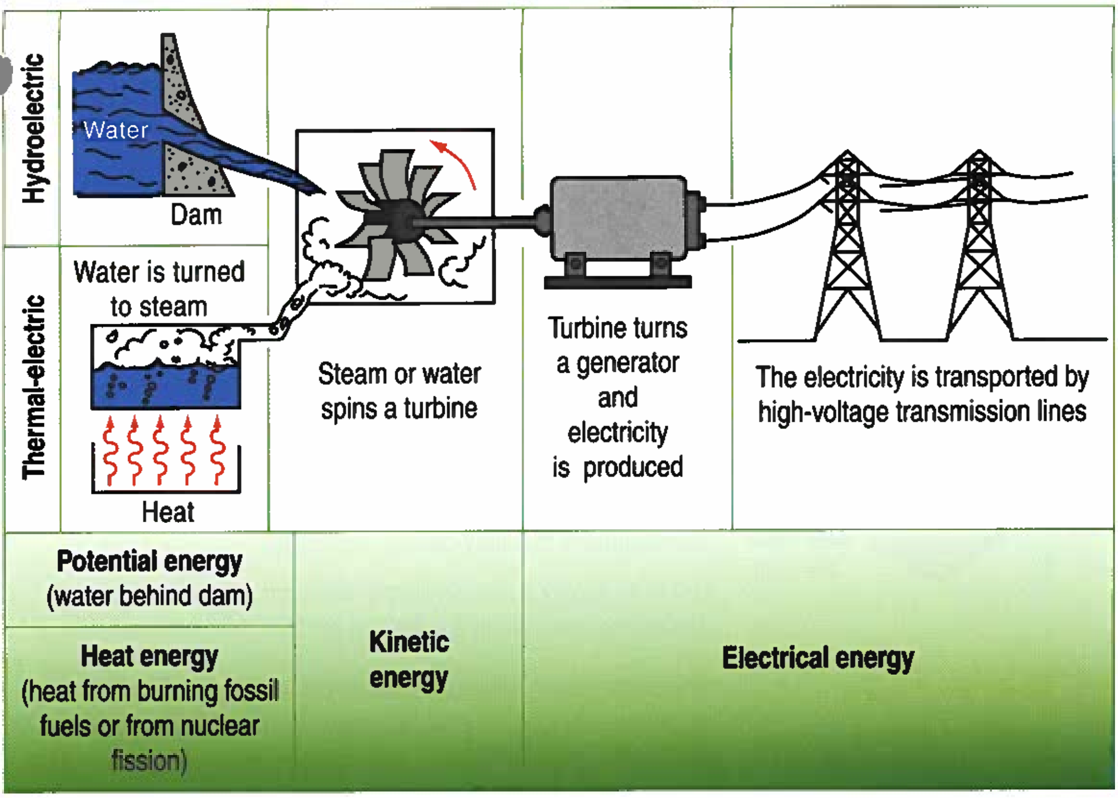
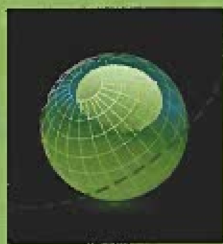


Figure 11-6. All generating stations are energy converters.

Most of the electricity used in homes and factories is produced either in hydroelectric or thermal-electric generating stations. There are, however, other methods. Friction, chemical action, light, heat, and pressure can also be used to generate electricity, but in much smaller amounts. See Figure 11-7.

Think Green

Green Power



Many power companies in the United States have begun offering a "green electricity" or "green power" option. This electricity is generated using "green" sources such as wind, hydroelectric, photovoltaic cells, landfill gas, or biogas.

In many areas, you can sign up to receive green power by calling your local utility company. The utility company charges a premium for the service. However, be aware that some systems are greener than others. For example, burning landfill gas produces greenhouse gases.

Therefore, before paying more for green electricity, find out exactly how the electricity is produced. Visit the Green Power Network Web site of the U.S. Department of Energy (eere.energy.gov/greenpower). This Web site contains links that show exactly what options are available in your area, along with the source of electricity for each.

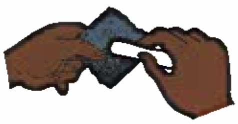
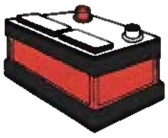
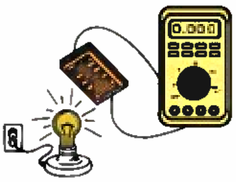
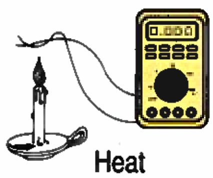
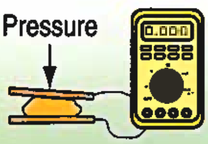
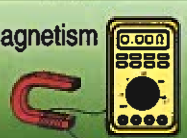
Method	Application	Discussion
 Friction	 Person pulling off a sweater	Friction causes static electricity. After walking across a carpet on a dry day, you become electrically charged. If you touch a grounded object, the static electricity will discharge, creating a spark.
 Chemical	Wet-cell battery   Dry cells	An acid or salt solution, called an *electrolyte*, removes electrons by chemical action from one piece of material and deposits them on another. Wet cells are used in cars and other vehicles. One of their advantages is that they can be recharged. Dry cells supply a comparatively small amount of electrical power and are used in a variety of portable electrical devices.
 Light	 Solar powered calculator	The photovoltaic cell is a sandwich of three layers. The outside layers are translucent, and the inside layer is iron with a disk of selenium alloy. When light is focused on the selenium, an electric charge develops between the selenium and the iron. Examples of use are automatic headlight dimmers and portable solar-powered calculators. A second way of using light to produce electricity is photoconduction. A common application of this principle is the control of street lights that come on automatically when daylight fades. Light energy applied to a material that is normally a poor conductor causes free electrons to be released in the material so it becomes a better conductor.
 Heat	 Thermocouple	A small electric charge is generated if the ends of two wires are twisted together and heated. This is the principle of a thermocouple. Commercial thermocouples use unlike metals welded together. They do not supply a large amount of current and cannot be used to produce electric power. They are used as temperature sensors.
Pressure 	 Barbecue lighter	A small electric charge is generated if quartz is placed between two metal plates while pressure is applied. One application is a lighter of the type used for lighting gas grills.
Magnetism 	 Generator	A generator uses magnetism to produce electricity. In an electric power generating station, generators are run by turbines.

Figure 11-7. Six ways to produce electricity.

Transmission and Distribution of Electricity

Generating stations are rarely found close to where the electrical energy is used. The electricity that comes to your home may have traveled a great distance.

After leaving the generating station, electricity is fed into a network of *transmission lines* and *distribution lines*, as shown in **Figure 11-8**.

Energy Conversions

Transmission lines, **Figure 11-9**, resist the flow of electrical energy, so some of the energy tends to be lost along the way. *Voltage* is a measure of electrical pressure, and *amperage* is a measure of the amount of current. Increasing voltage and reducing amperage greatly reduces the loss of energy from transmission lines. Therefore, when electricity is sent a long distance, it is more efficient and safer to send it as low-current, high-voltage electricity. A *step-up transformer* is used to increase the voltage for transmission. Each transformer consists of a pair of coils and a core.

Neither your home nor a factory can use electricity at the high voltage carried by transmission lines. It would destroy the wiring, appliances, and machines. The voltage must be reduced before current enters the distribution lines. *Step-down transformers* are used to reduce the voltage. The first drop in voltage occurs when electrical energy is transferred to

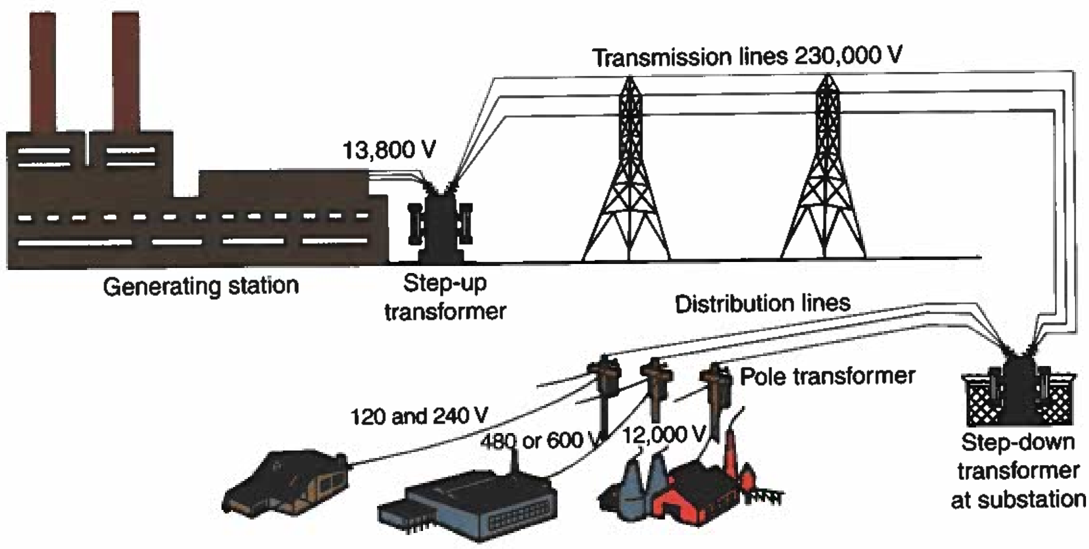


Figure 11-8. An electrical power transmission and distribution system.

Figure 11-9. Transmission lines are carried by towers. Insulators support the lines where they attach to the tower.

distribution lines. See **Figure 11-10**. Another step-down transformer reduces the voltage further when electrical energy is transferred from distribution lines to service lines. This transformer may be located on a pole or on the ground. See **Figure 11-11**. Electricity enters your home through a service line. It also passes through a meter and a main switch, as shown in **Figure 11-12**.

Figure 11-10. Distribution substations step down the voltage.

Figure 11-11. A service transformer further reduces the voltage in the distribution lines.

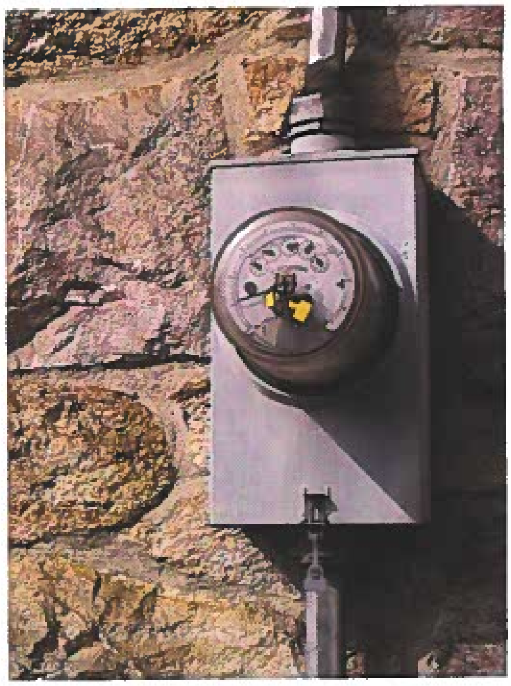


Figure 11-12. Electricity enters your home through a service line, meter, and main switch.

How Transformers Work

Basically, a transformer consists of two separated coils of wire around a magnetic core. **Figure 11-13** shows the construction of step-up and step-down transformers. One coil has more turns than the other. When the input voltage is connected to the coil with the least number of turns, the output voltage is increased (step-up). When the input voltage is connected to the coil with the greatest number of turns, the output voltage is decreased (step-down).

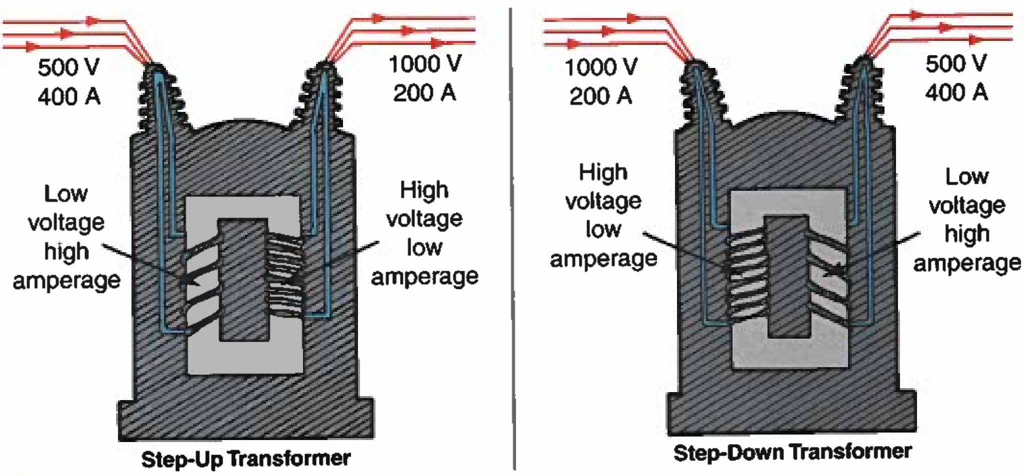


Figure 11-13. The number of turns on the coils in a transformer determine the amount of increase or decrease in the output voltage.

What Is Electricity?

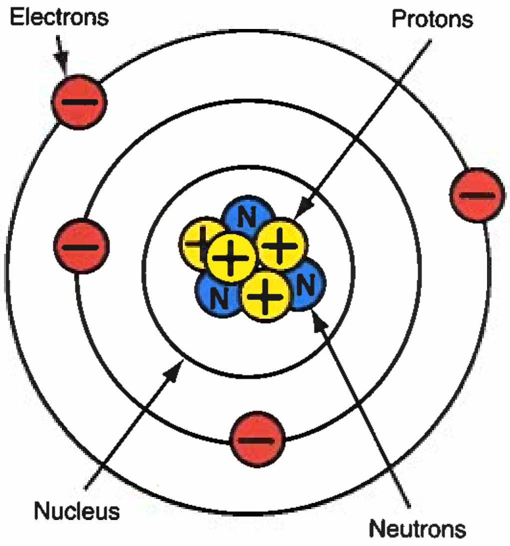
When you flip a light switch, electricity flows through wires and lights a bulb. What exactly is it that flows through the wire when the switch is turned on? There is no perfect answer. A scientist would say that electric current consists of a flow of electrons. What does this mean?

One explanation is called the *electron theory*. As described in Chapter 10, everything around us is made from atoms. Atoms are made of even smaller particles called protons, electrons, and neutrons. The protons have a positive charge, and the electrons have a negative charge. Neutrons have no charge and play no role in electricity.

An atom normally has the same number of electrons as protons. The negative and positive charges cancel each other. Such atoms are electrically neutral. See **Figure 11-14**.

Metal wires conduct electricity because the outer electrons in each atom are not tightly bound. They can move from atom to atom. Metals "conduct" electricity as these electrons move. When a metal wire is connected in a circuit, the free electrons can all be pushed in the same direction. This flow of electrons is called an *electric current*. See **Figure 11-15**.

Figure 11-14. Protons and neutrons make up the nucleus of the atom. Electrons orbit around the nucleus.



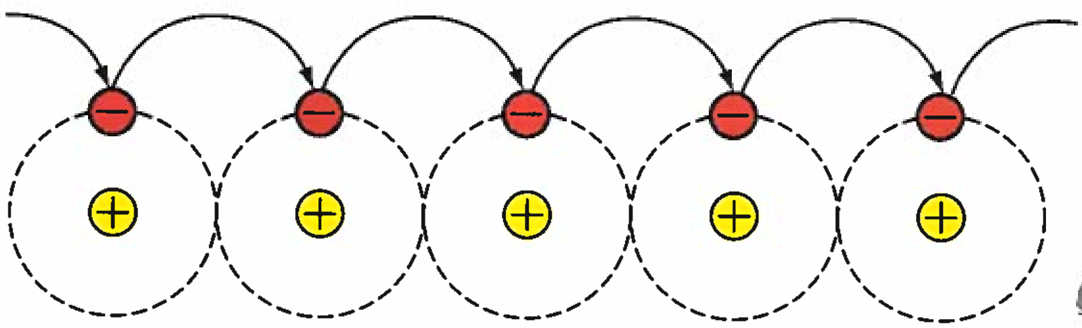


Figure 11-15. The movement of electrons occurs when a force is applied to one end of a wire. The free electrons move from one atom to the next, resulting in electric current.

A *conductor* is a material that allows an electric current to flow easily. Suppose that electrons are made to flow from one end of a metal wire to the other. Electrons can move through the wire, which acts as a conductor. The end that loses electrons becomes positively charged—the positive terminal. The end that gains electrons becomes negatively charged—the negative terminal. See **Figure 11-16**.

Why are electrons able to move through a wire? There are two reasons:

- A force pushes them along a path.
- There is a closed path, called a *circuit*, in which they can move.

In a circuit, an *electromotive force (EMF)* pushes electrons through a conductor. We also call this force *voltage*. The two most common sources of EMF are generators and chemical reactions. Generators use magnetism and mechanical energy to produce electricity. Dry cells and batteries use chemical reactions to produce electricity. These two sources provide most of the electricity that we use. Other sources of EMF are friction, light, heat, and pressure. (Look back at **Figure 11-7**.)

Magnets and Magnetism

The production of electricity depends on magnets and magnetism. *Magnetism* is the ability of a material to attract pieces of magnetic materials, such as iron or steel. Magnets do not attract nonmagnetic materials, such as aluminum, copper, glass, paper, and wood. See **Figure 11-17**. Magnets fall into three different groups: natural magnets, artificial magnets, and electromagnets.

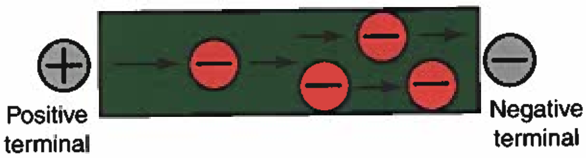


Figure 11-16. The terminal with a surplus of electrons is negative. The terminal with a shortage of electrons is positive.

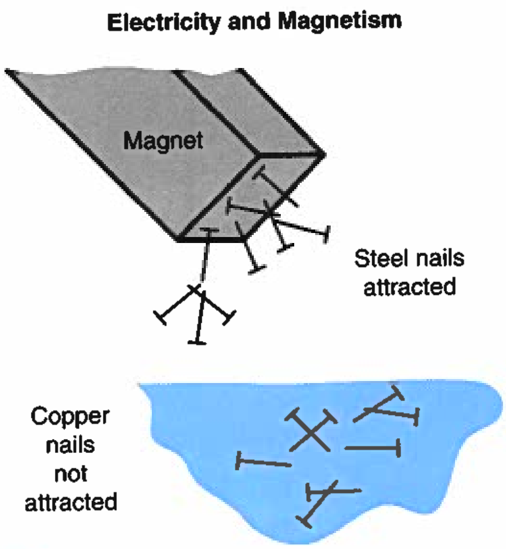


Figure 11-17. Magnets attract iron and steel, but not wood or other nonmagnetic items.

Math Application

Calculating the Cost of Electricity

Reading an electric bill is an excellent way to understand how much electricity your household uses each month. Electric utility companies usually have a key on the bill that helps customers understand what each entry means.

Normally, a bill has at least two readings: the previous reading and a current usage reading. These amounts have been read from the meter by an electric company employee. The readings are recorded in kilowatt-hours (kWh). The company bills the customer for the difference in the two readings at the rates marked on the bill.

An electric bill provides enough information to perform several calculations. To find the average kilowatt-hours used per day in any month, divide the number of kilowatt-hours used by the number of days. To find the cost per day, divide the amount of the bill by the number of days included in the bill. To find the cost per kilowatt-hour, divide the total amount of the bill by the number of kilowatt-hours.

Math Activity

The following information is from one family's bills for one year's supply of electricity. Use the information to practice calculating the cost of electricity by answering the questions below.

From	To	Days	kWh	$ Amount
08-07-2009	09-04-2009	28	360	34.22
09-05-2009	10-06-2009	31	420	35.17
10-07-2009	11-11-2009	35	680	56.91
11-12-2009	12-10-2009	28	710	59.18
12-11-2009	01-12-2010	32	990	82.04
01-13-2010	02-11-2010	29	920	77.58
02-12-2010	03-15-2010	31	1040	87.88
03-16-2010	04-13-2010	28	830	75.90
04-14-2010	05-11-2010	27	500	47.35
05-12-2010	06-09-2010	28	430	39.78
06-10-2010	07-07-2010	27	320	30.19
07-08-2010	08-06-2010	29	310	30.95

1. Find the average number of kilowatt-hours used per day from: (a) September 5 to October 6; (b) January 13 to February 11. Carry out your calculations to four decimal places.
2. Find the daily cost of electricity from December 11 to January 12.
3. Find the cost per kilowatt-hour from: (a) November 12 to December 10; (b) July 8 to August 6. Round the cost to the nearest one-hundredth (to the nearest penny).
4. Calculate the total number of kilowatt-hours used for the entire year and the total cost.

Natural Magnets

Natural magnets, such as lodestone, occur in nature. Lodestone is a blackish iron ore (magnetite). Its weak magnetic force varies greatly from stone to stone.

Artificial Magnets

Artificial magnets, also called *permanent magnets*, are made of hard and brittle alloys. Iron, nickel, cobalt, and other metals make up the alloys. The alloys are strongly magnetized during the manufacturing process.

Artificial magnets come in many shapes and sizes. The most common are horseshoe magnets, bar magnets, and magnets used in compasses. See **Figure 11-18**.

Natural and artificial magnets retain their magnetism indefinitely. A bike computer is a simple example of the use of magnets. The sensor attached to the bike's front fork can detect each time a magnet attached to a front wheel spoke passes the sensor. The computer uses this information to calculate the number of times the wheel turns. From this, it calculates the cyclist's speed, distance traveled, average speed, and fastest speed.

Electromagnets

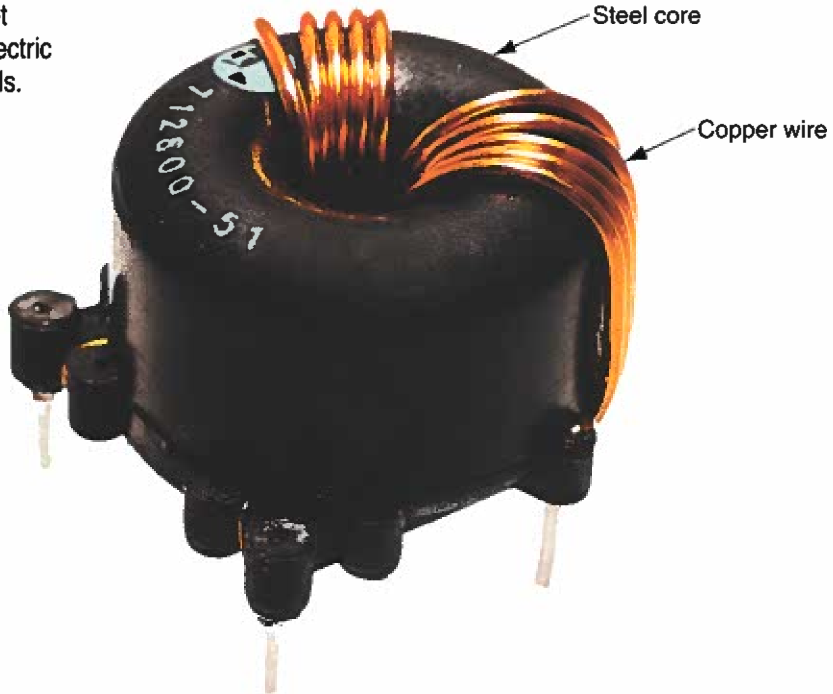
Electromagnets are magnetized by an electric current. They consist of two main parts. One is a core of special steel. The other is a copper wire coil wound on the steel core. See **Figure 11-19**. Unlike permanent magnets, electromagnets can be turned on or off. Their magnetic force can be completely controlled.

For example, metal detectors work by creating magnetic fields. When a metal detector's electromagnetic field encounters a metal object, such as a lost coin, its own magnetic field generates a smaller magnetic field around the object. When this happens, it makes a sound to alert the user.

A B

Figure 11-18. Three common types of artificial magnets. Which of these magnets is (a) a horseshoe magnet, (b) a bar magnet, and (c) a magnetic compass needle?

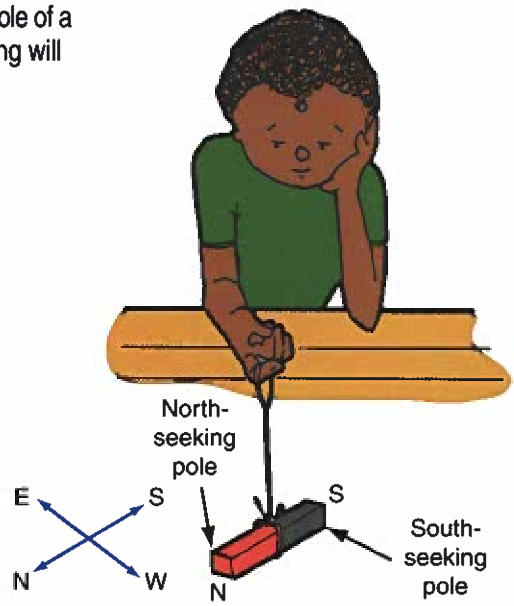
Figure 11-19. An electromagnet has a magnetic force only when electric current is sent through the wire coils.



How Magnets Act

Figure 11-20 shows a bar magnet suspended from a loop of thread. Held this way, the magnet twists until it is lined up in a north-south direction. The end that points toward the north is called the north-seeking pole. The end that points toward the south is called the south-seeking pole.

Figure 11-20. The north pole of a bar magnet that is free to swing will always point north.



If two magnets are suspended so that the north pole of one is close to the south pole of the other, the poles attract one another. See **Figure 11-21**. This is the first law of magnetism. It states that unlike magnetic poles attract each other.

If the north poles come close to one another, the magnets push away from each other. This is the second law of magnetism. It states that like magnetic poles repel one another. See **Figure 11-22**.

Lines of Force

Invisible lines of force surround a magnet. Although you cannot see them, you can prove they exist. Place a sheet of paper over a magnet and sprinkle iron filings on the paper. When you tap the paper gently, the small iron particles form a distinct pattern. See **Figure 11-23**. The lines of force shown by the iron filings take the shape shown in **Figure 11-24**.

Now place the two magnets end to end and repeat the experiment with iron filings. The lines of force demonstrate the two laws of magnetism. See **Figure 11-25**.

Magnetism and Electric Current

An electric current passed through a wire creates a magnetic field around the wire. Magnetism produced by this means is called *electromagnetism*. This principle is used to make the electromagnet in **Figure 11-26**.

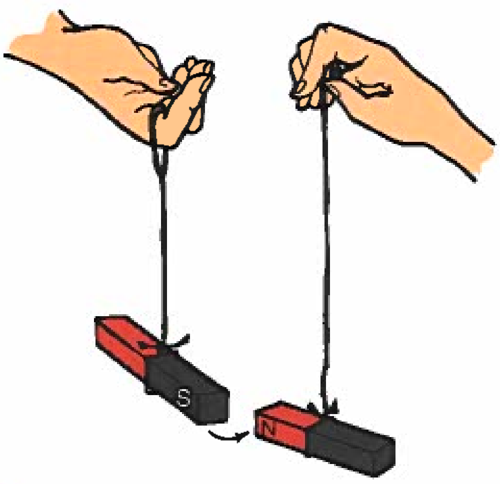


Figure 11-21. Unlike magnetic poles attract.

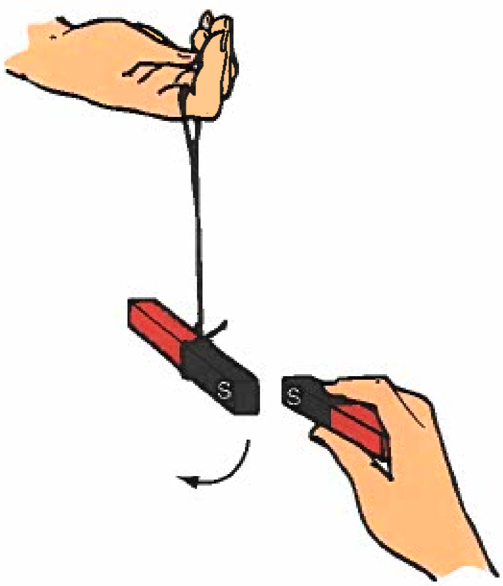


Figure 11-22. Like magnetic poles repel each other.

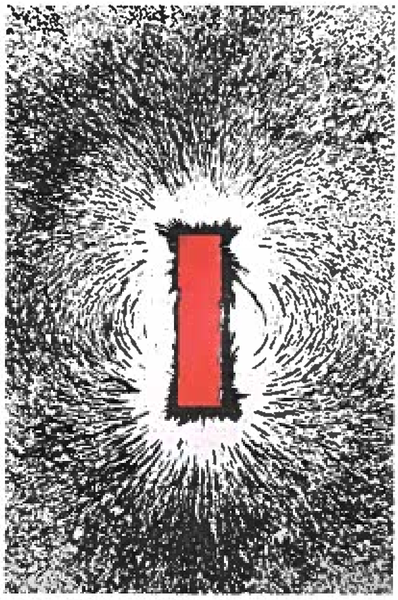


Figure 11-23. Iron filings show the lines of force around a magnet.

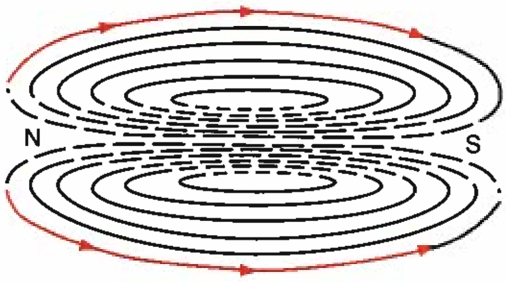


Figure 11-24. Note the pattern and direction of the lines of force.

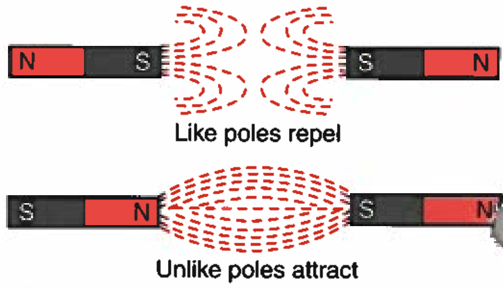


Figure 11-25. Try this experiment with two magnets and iron filings.

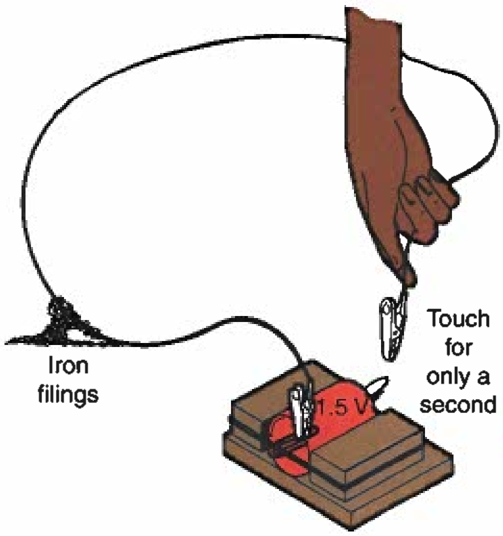


Figure 11-26. To produce a magnetic field, connect a wire to a dry-cell.

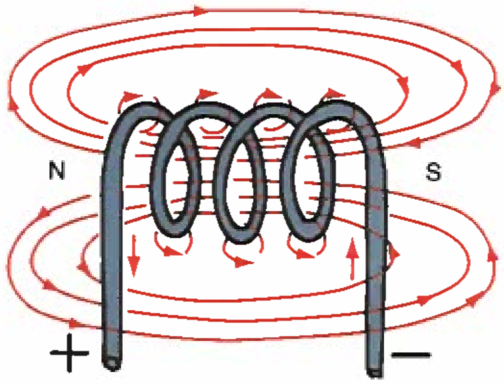


Figure 11-27. Coiling the wire shown in Figure 11-26 creates a magnet with positive and negative poles.

If the wire in Figure 11-26 is wound to form a coil, it becomes a magnet, as shown in Figure 11-27. The magnetic strength of this coil depends on the strength of the current and the number of loops in the coil. By changing these factors, you can control the magnetic strength of the coil.

If a wire is wound around a core of magnetic material, such as a soft iron nail, the nail becomes an electromagnet. It remains strongly magnetic only as long as there is current in the wire. See Figure 11-28.

> **WARNING:** The demonstrations shown in Figure 11-26 and Figure 11-28 should only be done by your teacher. A carbon-zinc cell should be used. **NEVER** use an alkaline cell. It may explode.

Generators

A generator is the most practical and economical method today of producing electricity on a large scale. It uses magnetism to cause electrons to flow.

To see this in action, connect a length of copper wire to a milliammeter. As shown in Figure 11-29, move part of the wire loop through a magnetic field. A small current flows while the wire is cutting across the magnetic field.

The strength of the current depends on two things. One is the strength of the magnetic field. The other is the rate at which the lines of force are cut. The stronger the magnetic field or the faster the rate at which the lines of force are cut, the greater the current.

The direction of electron flow depends on the direction in which the lines of force are cut. Look at Figure 11-29 again. When the wire moves down through the lines of force of the magnet, electrons flow in one direction. When the wire moves up, electrons flow in the opposite direction. The end that loses electrons becomes positively charged. The end that gains electrons becomes negatively charged.

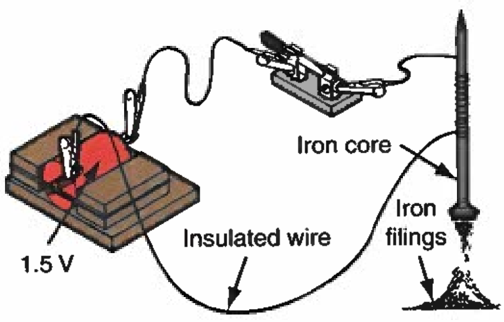


Figure 11-28. In this electromagnet, the nail remains magnetized as long as current flows through the coil.

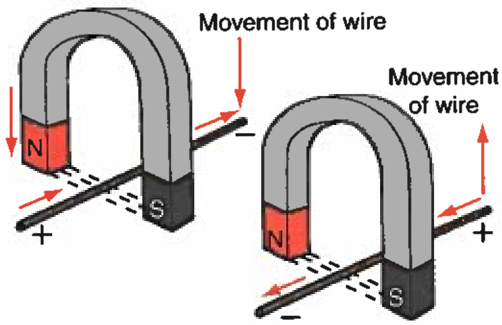


Figure 11-29. Moving a wire through a magnet creates a small current in the wire.

Alternating Current

Alternating current (AC) is electron flow that reverses direction on a regular basis. It is the type of current you use in your home. It is the type of current produced by power stations. How is it produced? This will become clear as the basic operation of a generator is explained.

Figure 11-30 shows a basic generator. It is no more than a loop of wire turning clockwise between the poles of a magnet. Remember that current is produced only when a wire cuts through lines of magnetic force.

With the loop (wire) in position A, no lines of force are cut. The generator produces no current. As the loop continues turning, it reaches position B. At this point, one side of the loop moves downward through the lines of force. At the same time, the other side of the loop is moving up through the lines of force. Because the wire is a closed loop, current travels through it in one direction.

As the loop reaches position C, half a revolution is completed. As in A, there is no current. Why? No lines of force are being cut.

The loop continues to turn until it reaches position D. The two sides once more cut lines of force. There is a difference, however. The side that moved downward before is now moving upward. Likewise, the side that moved upward before is now moving downward. What happens? The electron flow reverses. Because the direction of flow alternates as the loop turns, the current produced is called *alternating current*.

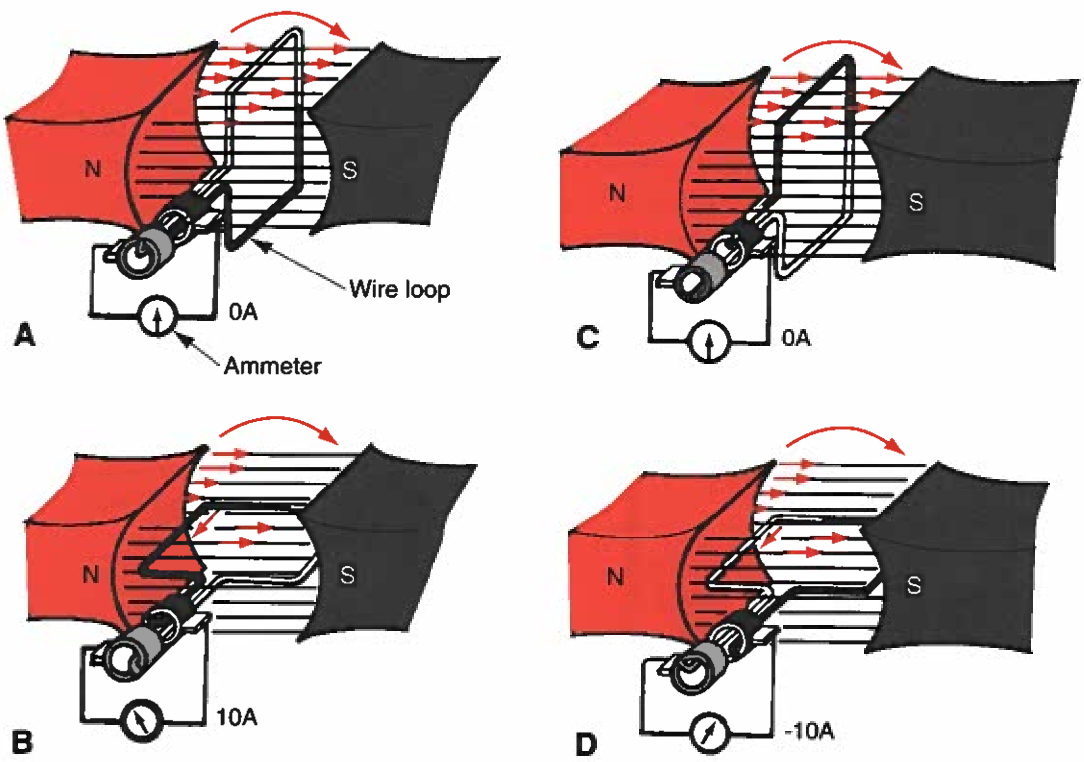


Figure 11-30. A basic AC generator.

Electricity produced by the generator must have a path, or circuit, along which it can flow. Therefore, the terminals (ends) of the loop must always be in contact with an outside wire. This outside wire is stationary. The contact is made with slip rings and brushes.

A separate slip ring is permanently fastened to each terminal of the wire loop. Each slip ring turns with the loop. A brush is placed against each slip ring. As the slip rings turn, the brushes maintain rubbing contact with them. The wire forming the stationary part of the circuit is attached to the brushes. Electrical devices, such as a light bulb, are connected to the external part of the circuit. See **Figure 11-31**.

Current produced in the loop of the generator flows through a slip ring and brush into the external circuit. It travels through the electrical device. Then it returns to the generator through the other brush and slip ring.

Generators at large generating stations are more complex than the loop generator shown in this chapter. However, their basic principle is the same. Generated current can be increased in the following two ways:

- Increasing the rate at which the lines of force are cut.
- Strengthening the magnetic field.

Therefore, many loops of wire are used instead of one. Powerful electromagnets supply the magnetic field.

For practical reasons, the loops are mounted around the inner surface of the generator housing. They remain stationary and are called the *stator*. The electromagnets are mounted around a rotating shaft. This assembly is called a *rotor*. It is placed inside the stator. Current is created by lines of force cutting across conductors instead of by a conductor cutting across lines of force. See **Figure 11-32**.

In alternating current, a *cycle* is a flow or pulse in one direction followed by a pulse in the opposite direction. The number of cycles per second is the *frequency* of the current. Frequency is measured in hertz. One hertz equals one cycle per second. In North America, with few exceptions, alternating current makes 60 complete cycles each second. In many European countries, the alternating frequency is 50 cycles per second.

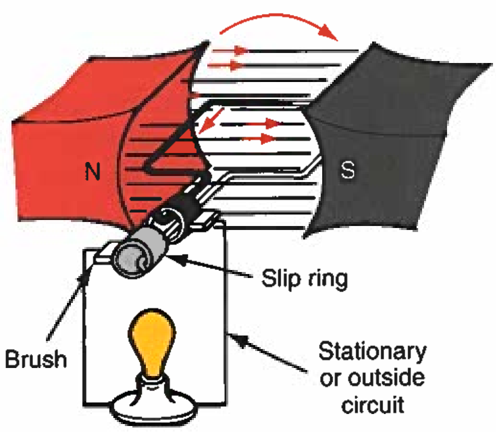


Figure 11-31. An AC generator with an external circuit.

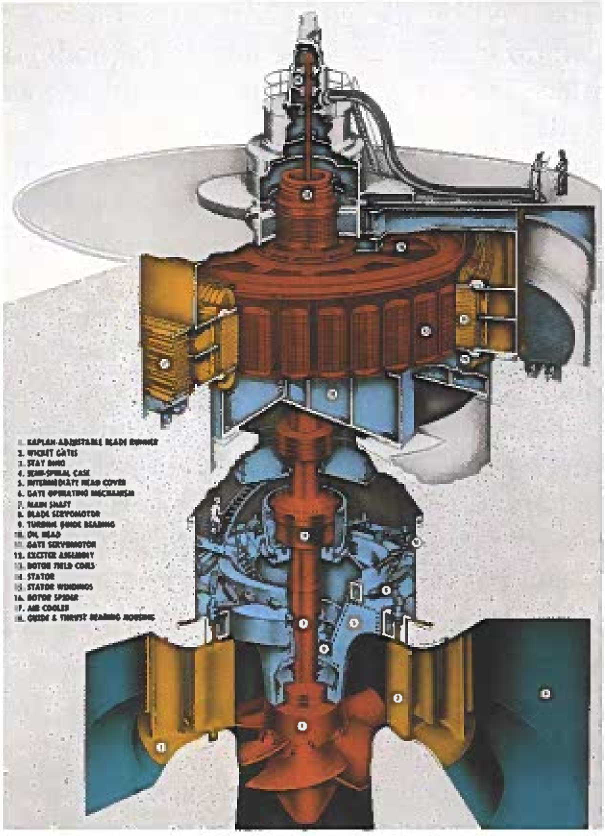


Figure 11-32. A cutaway view of a large generator. Which part is the rotor, and which is the stator?

About 90% of the electricity produced in the world today is alternating current. It is easier to generate in large quantities than direct current. Even more importantly, it is easier to transmit from one place to another.

Direct Current

Direct current (DC) is current that does not change direction in an external circuit. A direct current generator uses a single split ring. It replaces the two slip rings of an alternating current generator. Current in the loop still alternates. However, the split ring, called a *commutator*, sends current only one way through the circuit.

The brushes and commutator of a DC generator are shown in Figure 11-33. In part A, terminal 1 is contacting the brush connected to the negative side. Half a turn later, the current changes direction, as shown in part B. Terminal 1 is in contact with the brush connected to the positive side. Current through the external circuit continues in the same direction.

Each half of the commutator is attached to one of the wire loop's terminals. As the current changes direction, the rotating commutator switches the terminals from one brush to the other every half revolution.

Direct current is used in portable and mobile equipment, such as flashlights and car accessories. It is also used in electronic and sound reproduction equipment. Figure 11-34 shows a DC bicycle generator. A disadvantage of DC current is that it is difficult to transmit over long distances.

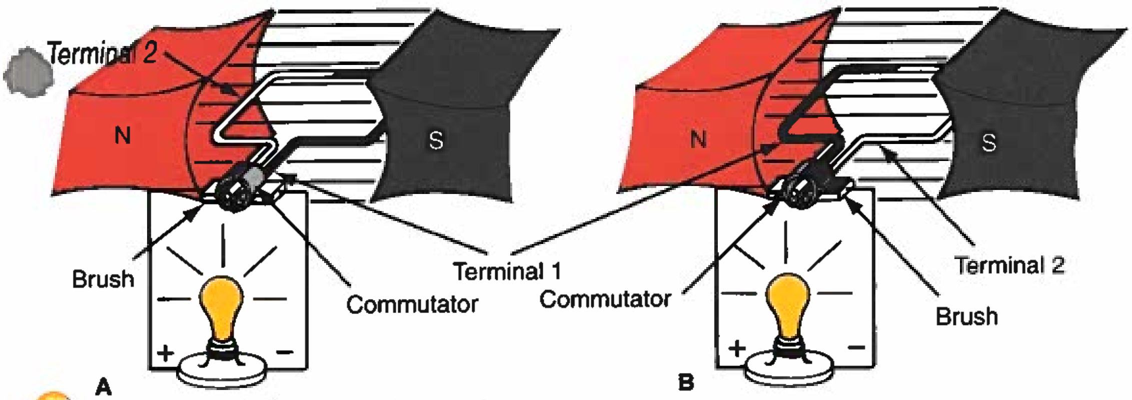


Figure 11-33. A direct current generator.

Figure 11-34. This bicycle light uses direct current supplied by the small generator. What advantage does this generator have over a light operated by a battery?

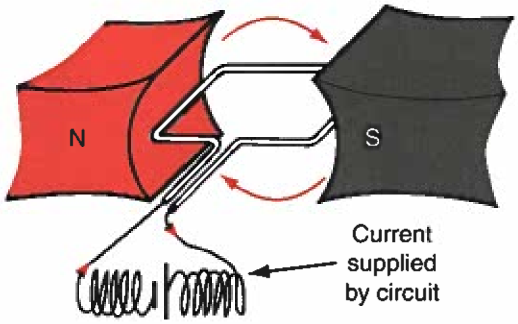
Electric Motors

In many ways, an electric motor is like a generator. However, while the two have similar parts, their purposes are different. A generator converts kinetic energy to electrical energy. An electric motor changes electrical energy to kinetic energy.

Both a generator and an electric motor apply the laws of magnetism. Both contain magnets and a rotating coil of wire. The coil of wire of an electric motor is placed in a magnetic field, as shown in Figure 11-35. The motor spins when a current is applied to the coil of wire.

What makes an electric motor run? Electrons flowing through the coil of wire of an electric motor cause a magnetic field around the coil. Remember the laws of magnetism? Unlike poles attract, and like poles repel. When current is introduced in the coil, the coil's magnetic field reacts with the magnets in the motor. The coil spins as it is attracted and repelled by the motor's permanent magnets.

Figure 11-35. An electric motor is much like a generator.



The coil spins for only part of a turn from the effects of magnetism. For an instant, the current stops and the coil coasts. The rotation would stop except for split copper ring, or commutator, that rotates with the coil. See **Figure 11-36**. When current starts up again, magnetic force keeps the coil turning.

Current passes into and out of the coil through brushes that press against the commutator. Current always passes down on the right side and returns on the left side of the coil. This switches the poles in the coil's magnetic field. The rotation then continues in one direction.

The brushes also serve a second purpose. Since they do not rotate, they prevent the wires from twisting.

Brushes are usually made from carbon. It is a good conductor and produces less friction than metal. The brushes are spring-loaded. Pressure from the spring ensures continuous contact with the commutator.

Cells and Batteries

What most of us call a battery is not a battery at all. It is really a cell. A battery is a set of cells connected together. A ***cell***, or ***dry cell***, has a single positive ***electrode***, a single negative electrode, and an electrolyte. A ***battery*** is a package containing several cells connected together.

The 9 V batteries used in portable electronic devices and 12 V car batteries are correctly called batteries. Inside a car battery are six 2 V cells. Inside a 9 V battery are six 1.5 V cells connected together. See **Figure 11-37**. When we refer to AA, C and D cells as batteries, we use the wrong term. They consist of only one 1.5 V cell.

Figure 11-36. The brushes of an electric motor are always in contact with the spinning commutator. This allows the electricity to flow into the commutator and into the coil.

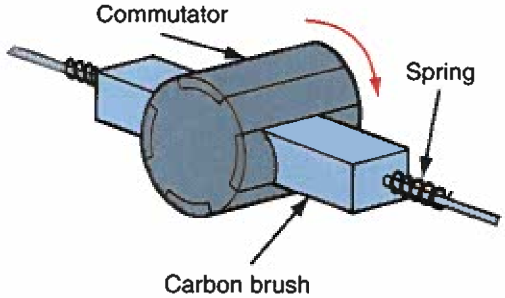


Figure 11-37. This cutaway of a 9 V battery shows that six 1.5 V cells are connected inside.

Voltaic Cell

The simplest type of cell is the *voltaic cell*. Two rods are immersed in a container filled with a solution of water and sulfuric acid. The mixture is known as an *electrolyte*. One of the rods is copper and the other is zinc. The acid reacts with both of the metals. See Figure 11-38.

Some of the atoms from the metals pass into the solution. Each atom leaves behind a pair of electrons. However, the zinc rod tends to lose atoms to the solution faster than the copper rod. Since the zinc rod builds up more electrons than the copper rod, it becomes negative. If the two electrodes are connected by a conductor, excess electrons flow along the conductor from the zinc to the copper. This flow of electrons produces an electric current. Since the flow of electrons is in one direction only, cells and batteries produce DC voltage.

Primary Cells

Cells are classified as either primary or secondary. A *primary cell* is one whose electrode is gradually consumed during normal use. It cannot be recharged. Primary cells are used in flashlights, digital watches, and some cameras.

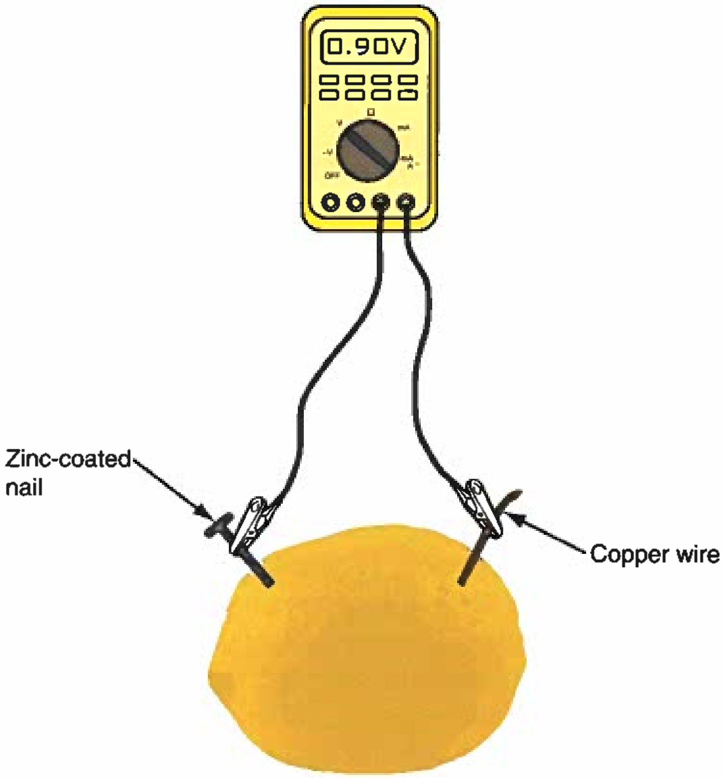
All of the primary cells used today use the same principles as the voltaic cell. They have three main parts: the electrolyte and two electrodes. See Figure 11-39. The electrolyte is a paste made of a very active chemical, such as a strong acid or base.

Inside the battery, two chemical reactions take place. One is between the electrolyte and the *cathode* (negative electrode). The other is between the electrolyte and the *anode* (positive electrode). These reactions change the chemical energy stored in the cell into electrical energy. When the chemical reactions have finished, the cell has no chemical energy left, and it can give no more electricity.

Science Application

Lemon Cell

You won't find a lemon battery powering any of your electronic equipment. The voltage is low compared to other batteries. However, all chemical cells work in the same way. Chemical reactions take place, changing chemical energy to electrical energy.



For example, in the lemon battery shown here, two chemical reactions are taking place: one at the copper electrode and one at the zinc electrode. The electrodes are placed in the electrolyte (in this case, lemon juice). In any battery, each pair of metal electrodes, together with the electrolyte, form a single cell. Therefore, the lemon shown is one battery cell.

Science Activity

To make a lemon cell, you will need two terminals:

- Copper, in the form of a copper wire or copper penny
- Zinc-coated nail or screw, or steel wire

Connect the two terminals to a voltmeter. The cell should measure about .5 V. Your lemon cell will not power a motor or even an incandescent light bulb, but what happens when you connect it to an LED? How can you increase the voltage so that the LED lights?

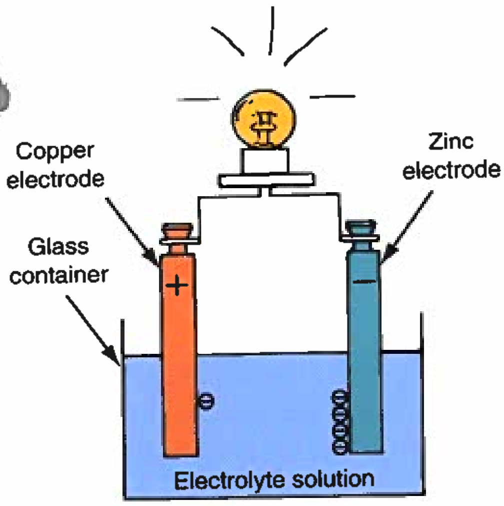


Figure 11-38. The copper and zinc electrodes react with the electrolyte solution at different rates. This results in an uneven buildup of free electrons that can be used to create an electric current.

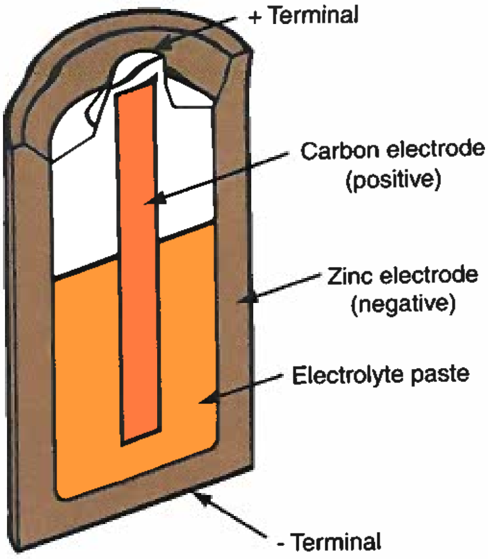


Figure 11-39. Cross-section of a primary cell.

Carbon-Zinc Cells

The carbon-zinc cell is one of the most common types of primary cell. It is also the least expensive, but it is short-lived. Carbon-zinc cells are produced in a range of standard sizes. These include 1.5 V AAA, AA, C, and D cells. Rectangular 9 V batteries also contain carbon-zinc cells. See **Figure 11-40**.

Alkaline Cells

Alkaline cells are produced in the same sizes as carbon-zinc cells. However, they can supply current longer.

Figure 11-40. These are typical primary cells. Shown from left to right: AA, C, and D cells.

Secondary Cells

A *secondary cell* is one that can store electrical energy to be used as needed, but can also be recharged after the electrical energy is used. See Figure 11-41. Lead plate electrodes are placed in a solution of sulfuric acid. A current passing through the lead plates produces chemical changes. The sulfuric acid solution gets stronger, and the cell becomes capable of producing an electric current. This is called "charging a cell." When charged, the cell can produce a current in a circuit.

As electricity is drawn from the cell, the chemical change that took place during charging reverses. However, the materials in the cell are not used up; they are only changed. Therefore, the entire process can be repeated.

Lead-Acid Batteries

Each pair of electrodes in a secondary cell can produce about 2 V. Most motor vehicles require 12 V to operate the starter motor. Therefore, six pairs of electrodes, or cells, must be connected together. Figure 11-42 shows a number of cells connected together to form a type of automotive battery known as a lead-acid battery.

Even after 100 years of commercial use, lead-acid batteries are still important. These batteries are used to power lights, radios, and all accessories in many vehicles. They also provide backup and emergency power for some electrical installations.

Nickel-Cadmium Batteries

Nickel-cadmium (NiCd) batteries were once the battery of choice for low-power portable products such as calculators and cameras. They can produce an energy density of between 45 and 80 watt-hours per kilogram (Wh/kg). *Energy density* is the amount of energy that can be stored in a battery per unit weight.

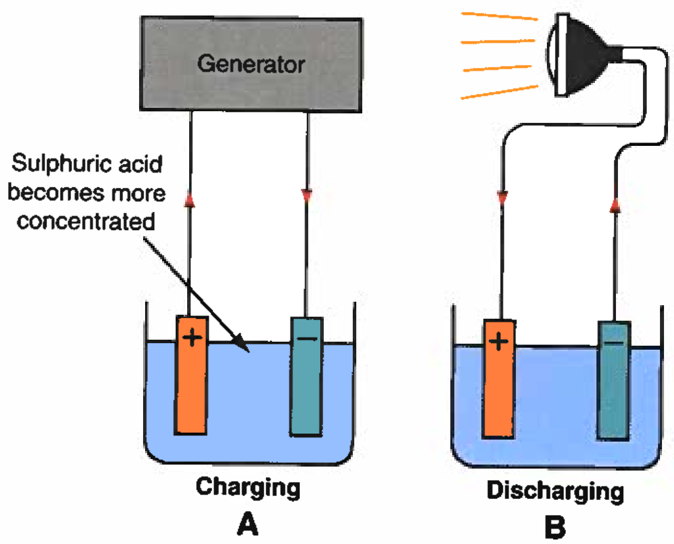


Figure 11-41. A secondary cell stores the energy it builds up during charging. It releases the energy as needed to produce an electric current.

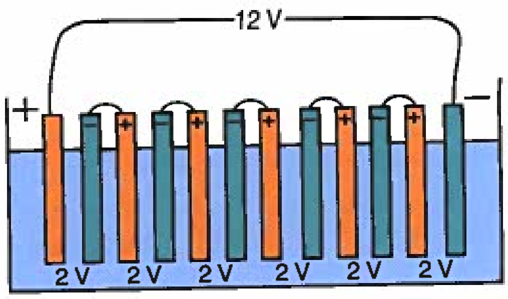


Figure 11-42. *Many automobile batteries are made by connecting six cells to produce 12 V.*

However, NiCd batteries have some major drawbacks. First, they "remember" the amount of discharge from previous use. This limits the recharge life of the battery. Second, cadmium is considered an environmental hazard and has to be disposed of carefully. For these reasons, NiCd batteries are being replaced by newer, more efficient types of secondary cells.

Nickel-Metal Hydride Batteries

Nickel-metal hydride (NiMH) batteries are similar to NiCd batteries. However, they can produce up to 120 Wh/kg. They are also less harmful to the environment. Therefore, NiMH batteries have replaced NiCd batteries for many applications. The main disadvantage of NiMH technology is that an NiMH battery tends to lose its charge in as little as two weeks, even if it is not used.

Lithium-Ion Batteries

Lithium-ion (Li+) batteries are now widely used to power laptop computers, cell phones, cameras, and many other portable devices. See **Figure 11-43.** They have many advantages over other rechargeable batteries:

- They provide a high energy density (180 Wh/kg), so the products they power can be recharged less often.

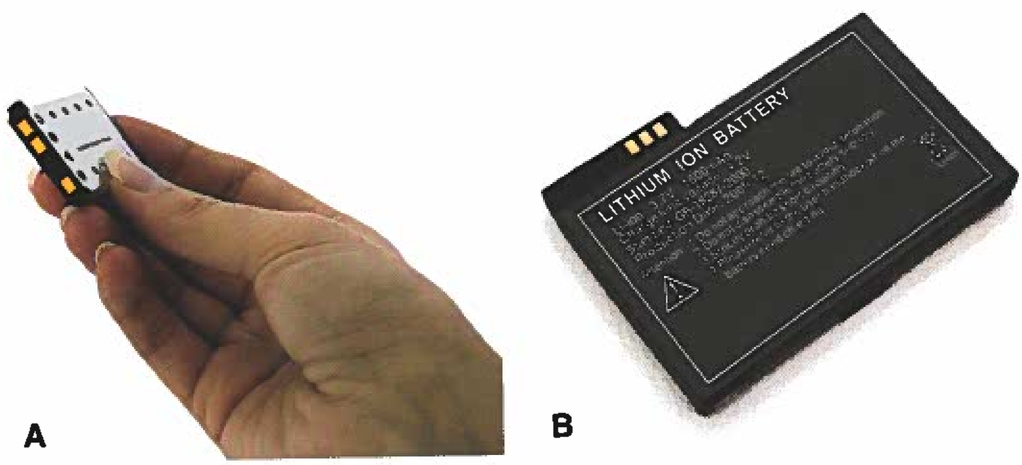


Figure 11-43. Lithium-ion batteries are now used to power most portable electronic devices because they are dependable and have a long battery life. A—Camera battery; B—laptop computer battery.

- They weigh less than other types of secondary cells and batteries.
- They remain rechargeable for a longer period of time.

Earlier Li+ batteries could be damaged by overcharging or overheating. Li+ batteries today incorporate devices that prevent overcharging and overheating, so they are very safe to use. However, because these batteries are more complex than NiCd and NiMH batteries, they are also more expensive.

End Note

People are using electricity for more and more purposes. In the past, electricity was generated mostly by petroleum- or coal-based plants. However, both petroleum and coal are fossil fuels and are nonrenewable resources. What will happen when the fossil fuels run out?

Forward-thinking people have begun to develop other methods of generating electricity. Solar energy and geothermal energy are two alternatives. These systems are already in use in some areas.

In the future, other technologies may also be used. Experiments are underway to produce electricity from such unlikely sources as sea algae and carbon dioxide. Researchers are also working with carbon nanotubes. These carbon molecules have been shown to produce large amounts of electricity under certain circumstances. In the not-so-distant future, perhaps our electricity needs will be met by cleaner, renewable sources.

Batteries, too, are constantly being improved. Researchers are hoping to replace chemical batteries by other advanced forms, such as tiny nuclear batteries. These will be powered by the natural decay of electrons given off by their radioactive source. Known as *betavoltaics*, they would be extremely small and long-lasting. They could be implanted almost anywhere. For example, they could be used in bridges, roadways, and buildings to monitor their condition and safety.

Summary

- Most electricity today is produced by hydroelectric and thermal-electric generating stations.
- Energy conversions are necessary to transport electricity over long distances while minimizing energy loss.
- According to the electron theory, electricity is produced when free electrons flow in the same direction, producing an electric current.
- Like poles of a magnet repel each other, and unlike poles attract each other.
- Generators move wire coils through a magnetic field to produce electricity.
- Electric motors are similar to generators, except that the purpose of an electric motor is to change electrical energy to kinetic energy.
- Batteries are made by connecting cells together to increase the total voltage output.

Reading Target

Preview and Prediction

Copy the following graphic organizer onto a separate sheet of paper. Do not write in this book. In the left column, record at least six predictions about what you will learn in this chapter. After you have read the chapter, fill in the other two columns of the chart.

What I Predict I Will Learn	What I Actually Learned	How Close Was My Prediction?

Test Your Knowledge

Write your answers to these review questions on a separate sheet of paper.

1. How are hydroelectric and thermal-electric generating stations similar? How are they different?
2. Describe where in a transmission and distribution system you might find each of the following voltages.
   A. 230,000 V
   B. 13,800 V
   C. 120 V
3. Briefly explain the electron theory of how electricity is produced.
4. State the two laws of magnetism.
5. What is electromagnetism?
6. What is the difference between alternating current and direct current?
7. How is the purpose of an electric motor different from that of a generator?
8. Explain the difference between a cell and a battery.
9. What is the difference between a primary cell and a secondary cell?
10. How many cells would a lead-acid battery need to produce 24 V?

Critical Thinking

1. Over a period of a year, a portable CD or DVD player uses a large number of cells (often referred to as *batteries*). What things could you do to reduce the amount of money you spend to power this device?
2. Science fiction is a form of literature that often "predicts" technologies of the future. Mary Shelley's book *Frankenstein*, first published in 1818, is one such classic. Obtain a copy of the book and find out how electricity is used in the plot. Then search the Internet to find new ways in which electricity is being used today. How does Shelley's use of electrical principles compare with the latest technologies?
3. Copy the following chart to a separate sheet of paper. Do not write in this book. Think about the advantages and disadvantages of each type of generating station. Then fill in the columns. List as many advantages and disadvantages as possible for each type. Then study your results. Which method of generating electricity do you think is best? Write a persuasive paragraph encouraging the use of this type of generating station.

Type of Station	Advantages	Disadvantages
Hydroelectric Station		
Fossil-Fuel Station		
Nuclear Station		

Apply Your Knowledge

1. Make a model to illustrate one method of generating electricity.
2. Describe the components of a network for the transmission and distribution of electricity. How many of these components can you see in your neighborhood?
3. Make sketches with notes to illustrate the following:
   A. An atom
   B. Electron flow
4. Perform the experiment illustrated in Figure 11-25. You can make iron filings by cutting steel wool into tiny pieces using an old pair of scissors. Expand the experiment by using two bar magnets with like poles together and with unlike poles together. You can fix the pattern of iron filings in place using hair spray.
5. Make a sketch to show how you would make an electromagnet.

Apply Your Knowledge *(Continued)*

6. Battery disposal has become an issue in recent years. Secondary cells, in particular, must be disposed of properly to avoid environmental and health hazards. Find out what the hazards are and how communities are currently dealing with these issues. How can these methods be improved? Develop and propose a new disposal plan that would be safe for humans and the environment.
7. Research one career related to the information you have studied in this chapter. Create a report that states the following:
   - The occupation you selected
   - The education requirements to enter this occupation
   - The possibilities for promotion to a higher level
   - What someone with this career does on a daily basis
   - The earning potential for someone with this career

   You might find this information on the Internet or in your library. If possible, interview a person who already works in this field to answer the five points. Finally, state why you might or might not be interested in pursuing this occupation when you finish school.

STEM Applications

1. **MATH** Ohm's law states that voltage is equal to current times the resistance in an electrical circuit ($V = I \times R$, where V = voltage, I = current, and R = resistance). You will learn more about Ohm's law in the next chapter. However, just by looking at the formula, you may be able to see how Ohm's law applies to transformers. Write a statement explaining how Ohm's law relates to the transmission and distribution of electrical power.
2. **ENGINEERING** Design and make an electrical system to power a head-mounted LED flashlight that could be worn at night on a camping trip. Consider whether to use a generator or battery-operated design. Find out how much voltage is needed and design the flashlight accordingly.
3. **SCIENCE** Although most metals conduct electricity, most electrical wires are made of copper. However, copper is not the metal that best conducts electricity. Find out more about how well common metals conduct electricity. Include copper, tungsten, zinc, aluminum, gold, silver, nickel, and platinum in your research. Make a chart to show your findings. Which metal is the best conductor of electricity? Why is copper used instead for most wiring applications? Which other metals, if any, could be used in electrical wires to conduct electricity efficiently?

CHAPTER 12

Using Electricity and Electronics

Better by Design

Leah Buechley designs wearable electronics

Leah Buechley is an American textile researcher who weaves, solders, and sews LEDs and electronics into cloth to build soft, flexible, wearable computers. For example, she constructed the LED bracelet shown here by weaving LEDs and beads together on a traditional beading loom. Computer chips and other electronic components are attached to the bracelet via custom-made fabric circuit boards that Leah developed. Leah also designed a construction kit called the LilyPad Arduino that allows others to build their own computational (electronic) textiles.

An LED bracelet shows up well in dark environments. What e-fashion products would you design and make?

"I believe in learning, inventing, and designing through building and hands-on experimenting."