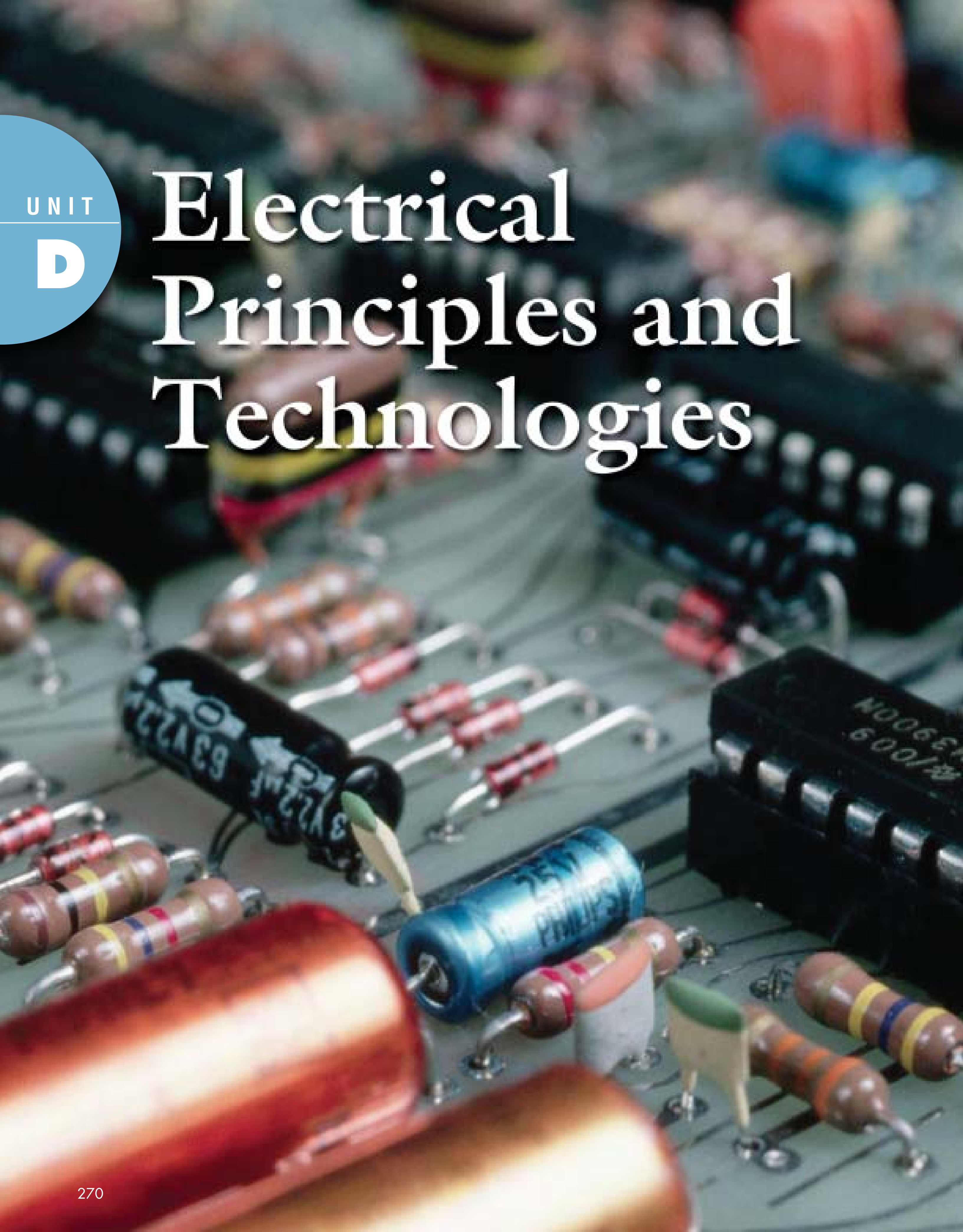
UNIT

D

Electrical Principles and Technologies



In this unit, you will cover the following sections:

1.0 Electrical energy can be transferred and stored.

1.1 Static Electricity
1.2 Current Electricity
1.3 Electrical Safety
1.4 Cells and Batteries

2.0 Technologies can be used to transfer and control electrical energy.

2.1 Controlling the Flow of Electrical Current
2.2 Modelling and Measuring Electricity
2.3 Analyzing and Building Electrical Circuits

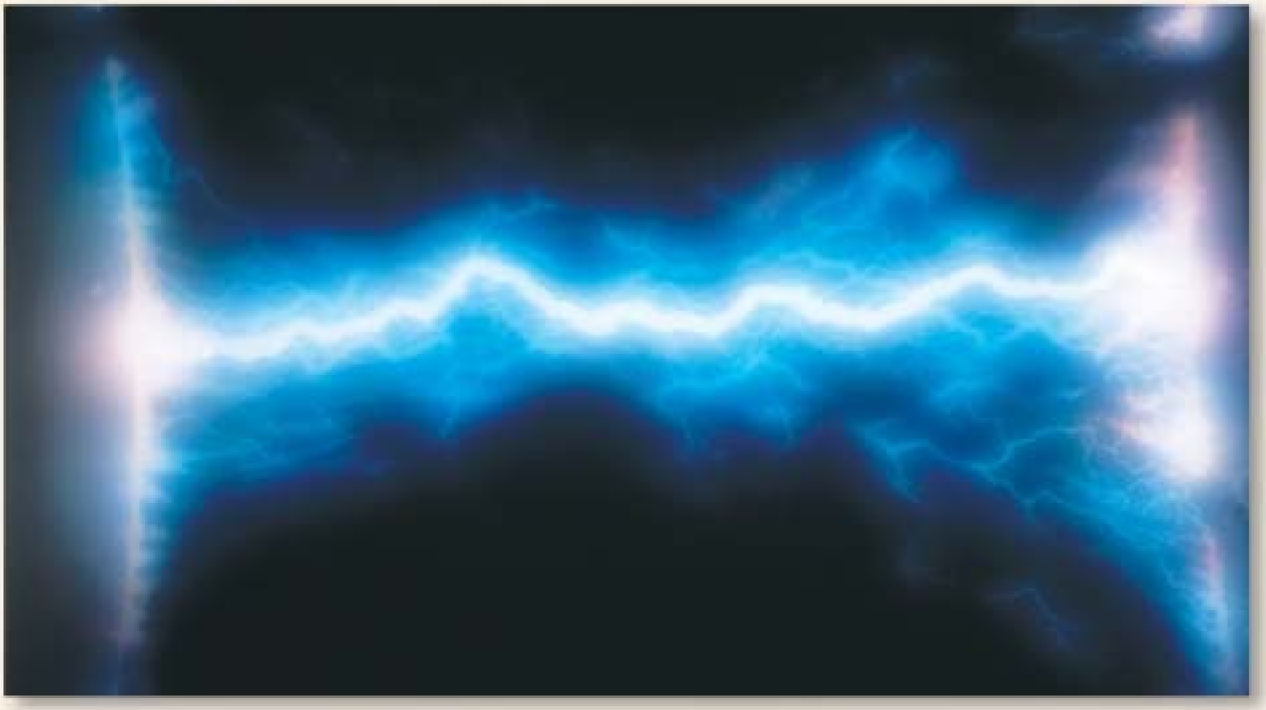
3.0 Devices and systems convert energy with varying efficiencies.

3.1 Energy Forms and Transformations
3.2 Energy Transformations Involving Electrical and Mechanical Energy
3.3 Measuring Energy Input and Output
3.4 Reducing the Energy Wasted by Devices

4.0 The use of electrical energy affects society and the environment.

4.1 Electrical Energy Sources and Alternatives
4.2 Electricity and the Environment
4.3 Electrical Technology and Society

Exploring



A Tesla coil

Electrical Energy

A Tesla coil vividly demonstrates electrical energy. This interesting device was invented over 100 years ago by Nikola Tesla, one of the pioneers of electricity. The Tesla coil can generate large amounts of electricity and create spectacular discharges. Amazing to watch, it operates with enough electricity to be very dangerous, even lethal. Tesla coils have often been used in films for special effects, but they are also used in laboratory studies of high voltage electricity.

Another device that you might have seen at the movies is the Jacob's ladder. It sometimes appears sparkling and crackling in the background as the villain tries to use huge machines and large amounts of electricity to take over the world.

The rising, crackling arcs of electricity in a Jacob's ladder are caused by electricity jumping from one piece of metal to another. When the electricity jumps, it heats the air that it passes through. This hot air rises and carries the electrical discharge upward. Unfortunately, this very impressive device has limited practical use. However, both the Jacob's ladder and the Tesla coil dramatically illustrate an important feature of electricity—its ability to move from place to place. Using technology, we can generate and move electricity to where it's needed in a wide range of applications that affect all parts of our lives.

A Jacob's ladder

QUICKLAB

CHARGE IT!

Purpose

To experience the nature of electrical forces

Procedure

Trial 1

1. Attach the cork to about 15 cm of thread. Hang the cork from the end of your desk by taping the opposite end of the thread to the edge.
2. Rub an acetate rod or plastic drinking straw with some wool or fur.
3. Slowly bring the rod close to the hanging cork. Record you observations.

Trial 2

4. Now rub the cork on the wool or fur, and then rub the acetate rod with the wool or fur.
5. Slowly bring the rod close to the hanging cork. Record your observations.

Trial 3

6. Turn on a water tap so that only a very thin stream of water comes out.
7. Rub the acetate rod with the wool or fur once again, and slowly bring the rod near the stream of water. Record you observations.

Questions

8. Describe the behaviour of the piece of cork and the water in this experiment.
9. Explain your observations for each trial.

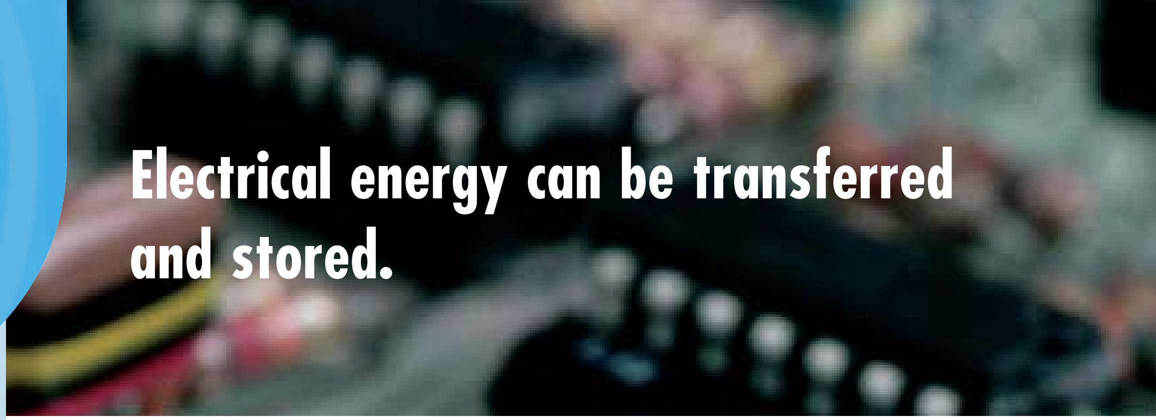
Materials & Equipment

- small pieces of cork or polystyrene
- tape
- thread
- acetate rod or plastic drinking straw
- wool or fur
- water tap

Focus On SCIENCE AND TECHNOLOGY

While studying this unit, you will be asked to organize your thoughts about electrical principles and technologies. Think about the following questions while you study the science of electricity and some of the technology that has developed from an understanding of this science. The answers to these and other questions about electricity will help you understand how to transfer, modify, measure, transform, and control electrical energy.

1. **How do we obtain and use electrical energy?**
2. **What scientific principles are involved in developing, selecting, and using energy-consuming devices?**
3. **How can the principles of electricity be applied in technology to promote efficient and effective energy use?**



1.0 Electrical energy can be transferred and stored.

Key Concepts

In this section, you will learn about the following key concepts:

- electric charge and current
- circuits
- electrical energy storage
- energy transmission
- measures and units of electrical energy

Learning Outcomes

When you have completed this section, you will be able to:

- distinguish between static and current electricity and identify evidence of each
- assess the potential danger of an electrical device by checking its voltage and amperage
- distinguish between safe and unsafe activities when dealing with electricity
- identify electrical conductors and insulators
- evaluate the use of different chemicals, chemical concentrations, and designs for electrical storage cells

The late evening weather report warns that thunderstorms are developing in your area. You step outside to view the skies and look for funnel clouds. You notice a dark gray cloud, and BOOM! A bolt of lightning strikes just down the street, the clap of thunder startling you. You decide to stay safe and go inside to bed. In your dark room, you pull your sweater over your head and see a shower of small sparks as the fabric rubs over your hair. You wonder for a moment: Are the sparks you see in the sweater related to the lightning you saw outside? Yes, they are! Both are examples of **static electricity**. In this section, you'll learn more about static electricity and the current electricity that powers the many devices you use in your home. You'll also learn about electrical safety.

 For Web links relating to 1.0, visit **www.pearsoned.ca/scienceinaction**

1.1 Static Electricity

You hurry down the hallway and reach for a doorknob. Zap! An electric shock jolts you. Your friend hands you a pair of scissors. Zap! Another shock. You have probably heard this type of shock called "static" or "static electricity." When you feel these jolts of static electricity, you are experiencing the same electrical force that causes lightning. This is also the electrical force that causes clothing to stick together and paper to stick to the glass on the photocopy machine.

The explanation of static electricity starts with the atom. Recall that all substances are made of atoms, and atoms are made of much smaller particles. If you have studied Unit B: Matter and Chemical Change, you know that some particles in an atom are electrically charged. The **proton** has a positive charge and the **electron** has a negative charge. The charges on the particles can cause either attractive or repulsive (pushing away) forces between the particles.

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Thales' Amber

The first person known to have experimented with static electricity was the philosopher Thales around 600 B.C. He found that rubbing amber, a fossilized tree resin, caused it to attract some materials. The word electricity is from the Greek word for amber, *elektron*.

*QUICK***LAB**

Static Charge

Purpose

To observe the characteristics of static electricity

Procedure

1. Sprinkle some confetti or gelatin powder in a small area on your desk. Push a plastic drinking straw through your hair several times and bring it close to the confetti or gelatin powder. Record your observations.
2. Inflate two balloons and knot the ends. Rub one side of each balloon on your hair or clothing. Hold the balloons by the knots and bring the rubbed surfaces slowly together. Turn one balloon so that its rubbed surface faces away from the other balloon. Again bring the balloons together. Record your observations.
3. If your classroom has a Van de Graaff generator (VDG), your teacher will assist you with the following experiments. In each case, put the materials in place, then turn on the generator, and record your observations.
   a) Tape the thin paper strips to the VDG.
   b) Place a stack of 3 aluminum pie plates on the VDG.
   c) Place a clear plastic cup full of polystyrene "peanuts" or "popcorn" on the VDG. Put a loose-fitting lid on top of the cup.
   d) Attach a metal rod to a lab stand and place it close to the VDG.

Questions

4 Provide an explanation for any movements that you observed.

5 How could you use the VDG to make someone's hair stand on end? Test your hypothesis with the VDG. Did it work? Explain why or why not.

Materials & Equipment

- plastic drinking straw
- confetti or gelatin powder
- 2 balloons
- Van de Graaff generator
- thin paper strips
- tape
- 3 aluminum pie plates
- clear plastic cup
- polystyrene "peanuts" or "popcorn"
- metal rod and lab stand

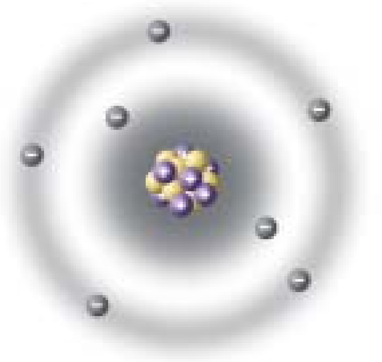

Figure 1.1 In an atom, the protons are in the nucleus. The electrons orbit the nucleus.

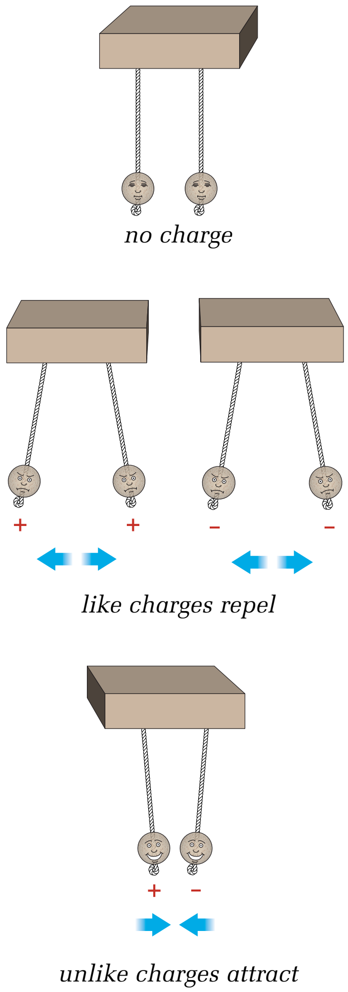

Figure 1.2 Charged particles exert force depending on their charge.

Electrical Charge

If you did the QuickLab on page 275, you noticed that some of the objects attracted each other and others repelled each other (pushed each other away). The objects reacted to each other in these ways because they are electrically charged.

You may have heard the phrase "opposites attract" in discussions about people. This is definitely true for electric charges. Opposite charges attract each other, and like charges repel each other. Figure 1.2 shows what happens when charged particles are close together.

Most objects have equal amounts of positive and negative charge, which makes them **neutral**. Sometimes an object has more of one type of charged particle than another. For example, an object with more electrons than protons is negatively charged. When this happens, we say that an object has built up a static charge. "Static" means "not moving" or "stationary." This type of charge does not flow like the electrons in an electrical current. You will learn more about electrical currents in subsection 1.2.

Charged objects cause **charge separation** when they are brought close to neutral objects. Rubbing a balloon on your head transfers electrons from your hair to the balloon. When you bring the charged side of the balloon near a wall, the negative charge of the balloon repels the electrons in the wall. This leaves the area of the wall closest to the balloon positive. The balloon and wall are attracted because of these opposite charges.

Electrical Discharge

Static electricity may not flow like a current, but it does sometimes discharge. The built-up charge on an object may be attracted to another object and jump to that object. This is what happens when you feel a shock as you reach for the doorknob after walking across a carpet. When your feet move across the carpet, electrons transfer from the carpet to your body. This excess charge of electrons in your body repels the electrons in the doorknob as you get close to it. The side of the doorknob closest to you becomes positively charged. As you move closer, the electrons in your hand are attracted to this positive charge on the doorknob. You may feel a shock or see a spark as you reach to touch the doorknob. The resulting spark is usually referred to as **electrical discharge**.

We can summarize the behaviour of electric charges in two laws. These laws describe what happens when two charged particles or objects are brought close together.

The Laws of Electrical Charges

- Opposite charges attract each other.
- Like charges repel each other.

ACTIVITY D-1

Inquiry

INVESTIGATING STATIC ELECTRICITY

The Question

What is the effect of charged objects on each other and on neutral objects?

The Hypothesis

Reword the question in the form of a hypothesis.

Materials & Equipment

- 2 vinyl strips
- tape
- ring stand
- paper towel
- 2 acetate strips
- beaker
- watchglass
- metre-stick

Procedure

1. Copy the following table into your notebook.

Hanging Object	Approaching Object	Observations
Charged vinyl	Charged vinyl	
Charged acetate	Charged acetate	
Charged acetate	Charged vinyl	
Metre-stick	Charged vinyl	
Metre-stick	Charged acetate	

2. Tape one end of a vinyl strip to the ring stand so the strip hangs down. Rub the strip with the paper towel to charge it. Now rub the other vinyl strip with the paper towel, and bring it close to the suspended strip. Record your observations in your table.
3. Repeat step 2, using the two acetate strips and the paper towel. Record your observations.
4. Bring one of the charged vinyl strips close to the suspended acetate strip. Record your observations.
5. Place the beaker upside down on the desk or table, and place the watchglass on top of the beaker. Balance the metre-stick so it is lying flat and centred on the watchglass. Bring a charged vinyl strip near, but not touching, one end of the metre-stick. Record your observations.
6. Bring a charged acetate strip near, but not touching, one end of the metre-stick. Record your observations.

Figure 1.3 Balance the metre stick on the watchglass on top of the beaker.

Analyzing and Interpreting

7. Usually, charged vinyl is negative, and charged acetate is positive. How does this information explain your observations?
8. Do your observations agree with the laws of electrical charges? Support your answer with your data.

Forming Conclusions

9. Describe the effect of charged objects on each other and on neutral objects. Use your observations in your description.

Applying and Connecting

The interaction between charged and neutral objects can lead to dangerous discharges. For example, helicopters build up a large static charge from their blades spinning in the air. Because of this, baskets lowered for sea rescues must touch the water before anyone approaches them. The static discharge could knock people overboard or stop their hearts.

reSEARCH

Cleaning the Air

In the early 1900s, factories with large smoke stacks were belching pollutants into the atmosphere. In 1907, Frederick G. Cottrell patented a device called the electrostatic precipitator. It not only cleaned the air, but also recovered products from the smoke that would otherwise pollute. Write a short biography of Cottrell, and a brief illustrated report on how electrostatic precipitators work. Begin your information search at www.pearsoned.ca/scienceinaction.

Van de Graaff Generators

Scientists often study electrical discharge with a device called a Van de Graaff generator (VDG). If you did the QuickLab earlier in this lesson, you may have used one of these generators. VDGs are particularly effective at building up static charge. They produce static build-up by using friction. Figure 1.4 shows how a VDG works. A rubber belt rubs on a piece of metal and transfers the charge to a sphere. The charge builds up on the sphere and transfers to you when you touch the sphere.

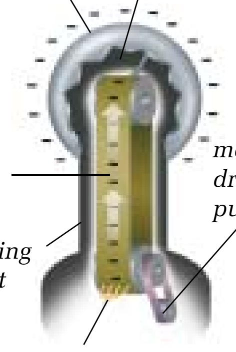

Figure 1.4 A Van de Graaff generator uses friction to build up a static charge on its sphere.

Check and Reflect

Key Concept Review

1. How does a proton differ from an electron?
2. What does it mean to be "statically charged"?
3. Explain how a Van de Graaff generator builds up a static charge.
4. a) What happens when like charges interact?
   b) What happens when unlike charges interact?

Connect Your Understanding

5. You rub your feet across a floor and electrons transfer from you to the floor. Are you now negatively or positively charged?
6. *A neutral object contains no charge.* Is this statement accurate? Explain.
7. Why is a neutral object attracted to a charged object?
8. You bring a negatively charged rod close to some tiny pieces of plastic. Some of the pieces jump up to the rod, but as soon as they make contact, they immediately fly away from the rod. Explain.

Extend Your Understanding

9. Large trucks that carry flammable liquids often have a metal wire or chain that drags on the ground. Why? (Hint: Have you ever been shocked when getting out of a car?)

1.2 Current Electricity

The electric eel is not really an eel, but it is definitely electric—and dangerous. Large specimens (they grow up to 2.4 m long) can discharge enough electricity to kill a human being. The electricity is produced by a special organ in the tail that contains thousands of modified muscle cells called *electroplaques*. Each electroplaque can produce only a small amount of electricity. But working together, all the electroplaques in the eel's body can produce large amounts of electricity to help the eel survive. The eel has no teeth and can eat only prey that isn't moving. When a prey animal comes close, the eel releases an electrical charge to stun it. These electrical flows are so strong they have even been known to knock down a horse!

Figure 1.5 The electric eel *(Electrophorous electricus)* uses electricity to kill or stun prey, for defense, and for communication.

Electrical Current

The electricity of the electric eel is similar to the static charges you have felt or the huge static charges of lightning. Unfortunately, static charges are not useful for operating electrical devices. They build up and discharge, but they do not flow continuously.

The steady flow of charged particles is called **electrical current**. This is the type of electricity needed to operate electrical devices. Unlike static electricity, an electrical current flows continuously, as long as two conditions are met. First, the flow of electrical current requires an energy source. Second, electrical current will not flow unless it has a complete path or **circuit** for the charged particles to flow through.

***QUICK*LAB**

Electrical Current

Purpose

To observe the characteristics of electrical current

Materials & Equipment

- 1 dry cell
- 5 wires
- 2 light bulbs

Procedure

1. Using any of the materials provided, make one light bulb light up.
2. Using the dry cell, one bulb, and one wire, make one light bulb light up.
3. Using any of the materials provided, make two light bulbs light up.
4. Make two light bulbs light up so that when you unhook one bulb, the other one goes out.
5. Make two light bulbs light up so that when you unhook one bulb, the other one stays on.

Questions TOOLBOX

6. Draw your set-up for each step from 1 to 5.
7. Write captions that explain what happened to the electricity in each step.

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The Challenge of Measuring Current

The first measurements of current were done with simple galvanometers. They detected current by using a compass needle. A current-carrying wire creates a magnetic field, which deflects a compass needle. However, Earth's magnetic field sometimes interfered with readings. In 1825, Italian physicist Leopold Nobili invented the astatic galvanometer, which greatly reduced the effect of Earth's magnetism. This new device provided more sensitive measurements.

Amperes

The rate at which an electrical current flows is measured in **amperes** (A). Often called "amp" for short, the ampere is named in honour of the French physicist, mathematician, and philosopher André-Marie Ampère. Most electrical devices around your home have a current of less than 15 A. For example, the current through an ordinary 60-W light bulb is 0.5 A. Microwave ovens usually use between 5 and 8 A, and electric kettles usually use 13 A. In contrast, a digital wristwatch uses a current of only a tiny fraction of an ampere, while a generating station produces many thousands of amperes.

A continuous flow of electrical charge can be produced by devices ranging from miniature cells in watches to huge generators in power stations. The key problem is how to move the charge from where it is produced to where it is needed. Fortunately, there are many materials that electrical charge can move through easily. Such materials are called **conductors**. Conduction of electricity through wires allows for the transfer of electrical energy from place to place.

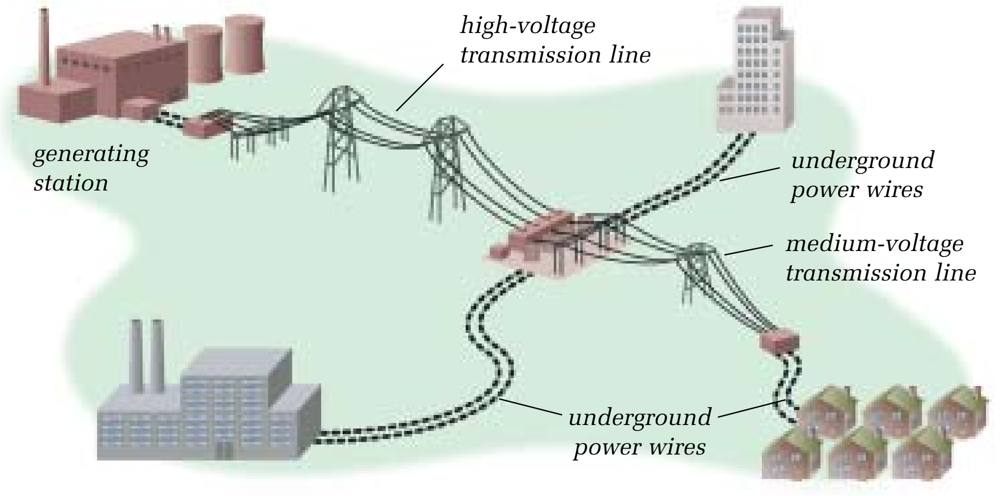

Figure 1.6 An electric power grid transfers energy from the generating station to the users. Multiple wires are needed at every part of the grid (including the devices you use in your home) because the whole grid is a complete circuit.

Circuits

Figure 1.7 shows a light bulb lit by electrical current flowing through a simple circuit. A **circuit** is a path that controls the flow of electricity. If you compare electricity with water again, the water system in your house is like an electrical circuit. The pipes and taps in the water system control the flow of water.

In most electrical circuits, the path that the electricity flows along is made of solid metal wires. But circuits can also include gases, other fluids, or other substances. A circuit usually includes a conductor, an energy source, and a **load**. The load is a device to convert electrical energy to another form of energy. For example, in Figure 1.7, the light bulb is the load. It converts electrical energy to light and heat.

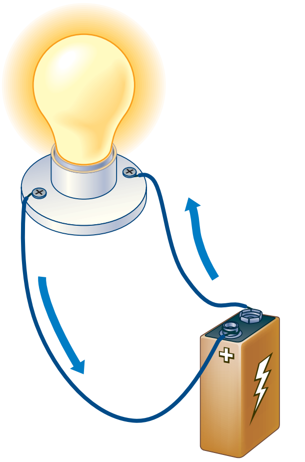

Figure 1.7 Current electricity flows continuously through a circuit.

Electrical Energy and Voltage

Electrical energy is the energy carried by charged particles. **Voltage** is a measure of how much electrical energy each charged particle carries. The higher the voltage is, the greater the potential energy of each particle. Voltage is also called "**potential difference**." The energy delivered by a flow of charged particles is equal to the voltage times the total charge of the electrons.

The unit of voltage is the **volt** (V), named for the Italian physicist Alessandro Volta. For safety reasons, most of the voltages in everyday devices are fairly low. Flashlights and portable stereos rarely use more than 6 V, almost all cars have a 12-V electrical system, and your home and school have 120-V wall sockets. On the other hand, industrial machinery operates at 600 V, and major electrical transmission lines can have over 100 kV.

Measuring Voltage

The simplest way to measure voltage is with a **voltmeter**. Many voltmeters have sensitive needles that can be damaged if connected improperly. Make sure to attach the red lead to the positive terminal and the black lead to the negative terminal.

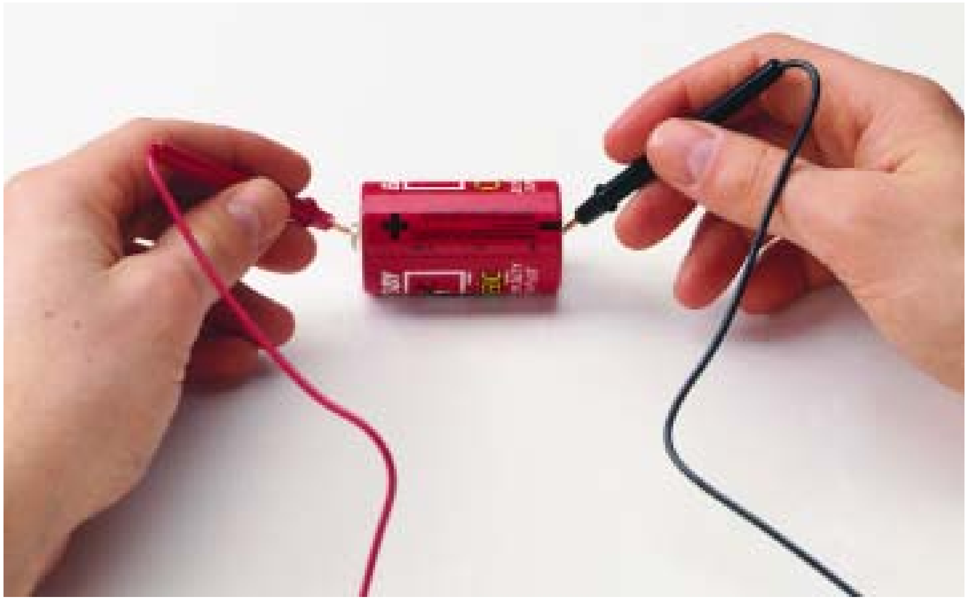

Figure 1.8 It's important to connect a voltmeter properly.

Some voltmeters have more than one red terminal. These are used to change the range of voltage readings on the voltmeter. For example, the meter could indicate either 0 to 5 V or 0 to 15 V, depending on which red terminal is used. If your meter has several ranges, you may not be sure which one to use. Start with the highest one and work down until you get a clear reading.

re**SEARCH**

Corona Discharge

High-voltage transmission lines sometimes have an eerie blue glow. Sailors saw this same glow around the tips of ships' masts before storms and called it St. Elmo's fire. Today it's called corona discharge. Find out more about corona discharge, and summarize your research as a magazine article. Begin your information search at www.pearsoned.ca/scienceinaction.

You may encounter several types of voltmeters. For example, some meters may give readings in millivolts. Each millivolt is 1/1000 of a volt (e.g., 30 mV is 0.030 V). Some meters have digital displays, which make the voltage values very easy to read.

Figure 1.9 Some voltmeters have more than one range of measurement.

Figure 1.10 A digital voltmeter display

SKILL **PRACTICE**

USING VOLTMETERS

Your teacher will provide you with cells of various sizes and shapes. Use the voltmeters you have in your class to test and report on the voltages of the cells. Note the voltage numbers that are written on the cells.

- Can you account for any difference between your voltage readings and the numbers on the cells?
- Suppose you connected any two of the cells in this activity. (Connect cells by placing positive and negative terminals together.) Can you predict what the voltage reading would be? Use your voltmeter to see if your prediction is correct. Explain your results.

Measuring Voltage with Computers

Another method of measuring voltage is with a voltmeter connected to a computer. With this device, you connect the terminals the same way as for other voltmeters, but your voltage reading appears on a computer screen.

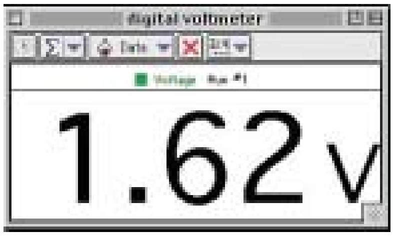

Figure 1.11 A voltage reading displayed on a computer screen

Check and Reflect

Key Concept Review

1. What is electrical energy?
2. How does current electricity differ from static electricity?
3. How would you describe voltage?
4. What are the units for measuring a) current and b) voltage?

Connect Your Understanding

5. You require a high-current battery to start a large tractor. While shopping for this battery, should you be more concerned with the battery's rating of volts or amps? Explain.
6. *A wire carrying more electrons will transfer more energy than a wire carrying fewer electrons.* Is this statement accurate? Explain.
7. Describe how electricity gets from the generating plant to an appliance in your home.
8. Electricity flows into a hairdryer when it is plugged into a socket. If electricity has been added to the hairdryer, why doesn't it keep operating for a while after being unplugged?

Extend Your Understanding

9. What is the reading on the voltmeter in Figure 1.12? Give your answer in both millivolts and volts.

Figure 1.12 Voltmeter reading for question 9

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Fulgurites

Lightning can be dangerous because it discharges so much energy. Lightning strikes can actually melt sand and rock when they hit the ground, creating intriguing glass-lined tubes call fulgurites.

1.3 Electrical Safety

In January 1998, eastern Ontario and western Quebec were hit by a massive ice storm. In many places, power lines and towers were knocked down. Such situations can be extremely dangerous because power lines carry electrons at thousands of volts—enough to seriously injure or kill anyone who comes close to them. You should never approach a downed power line.

Any person coming in contact with a power line may create an unintended path for the electricity. Such a path is sometimes called a **short circuit** because the current bypasses part of the normal circuit. If a power line goes down, the electricity goes off in the entire area served by that power line. Without a complete circuit, electricity can't flow. However, if the electricity can find another path, such as through a person's body to the ground, then it will take that path.

Figure 1.13 Downed power lines in Quebec during the 1998 ice storm

The Dangers of Electrical Shock

To get an idea of how dangerous a current flowing through your body may be, consider two important aspects of electricity: voltage and amperage. High voltage is more dangerous than low voltage; for example, 50 000 V are more likely to kill than 10 V. However, even small voltages can kill if the shock carries a significant number of amps. The number of amps is much more important than voltage when assessing the potential danger of an electrical shock. If 0.001 A passed through your body, you would likely not feel it. Current in the range of 0.015 A to 0.020 A will cause a painful shock, and loss of muscle control. This means a person grabbing a wire at this current level may not be able to let go. Too much electricity flowing through the body can have extremely harmful effects, including burns and damage to the heart. Current as low as 0.1 A can be fatal.

In Figure 1.14, a downed power line is touching the truck, but the driver is not electrocuted as long as he stays in the truck. If he must leave, he should jump free, not step out. Stepping to the ground would provide a path for the electricity to flow through him to the ground.

Figure 1.14 The driver should stay in the truck and wait for help.

Factors Affecting Electrical Shock

The danger of electrical shock varies, depending on the situation. The current is greater when it can flow easily. Current does not flow easily through **insulators** such as wood, rubber, and air. Other substances such as mud and damp soil conduct electricity somewhat. Thus, you might feel just a tingle if you touch an electrified fence on a dry day when you are wearing running shoes. But you could get a nasty shock if you touch the fence when you are barefoot in the rain.

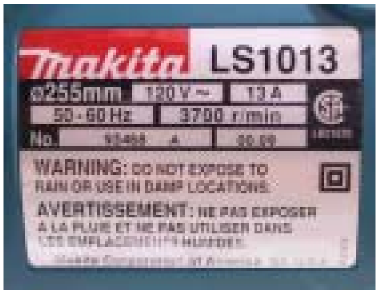


Figure 1.15 A Canadian Standards Association label listing voltage and current for an appliance

Protecting Yourself from Electrical Shock

Every plug-in device sold in Canada must have a label listing what voltage it requires and the maximum current it uses. Usually, this label is on the back or bottom of the appliance. The higher the voltage or current, the more harm the device can do if it malfunctions.

However, the amperage rating doesn't have to be high for you to get a shock. If there is a short circuit or if the insulation is damaged, you could get a shock from the electricity before it goes through the device. So, no matter what the current rating of the device is, you should always take electrical safety seriously.

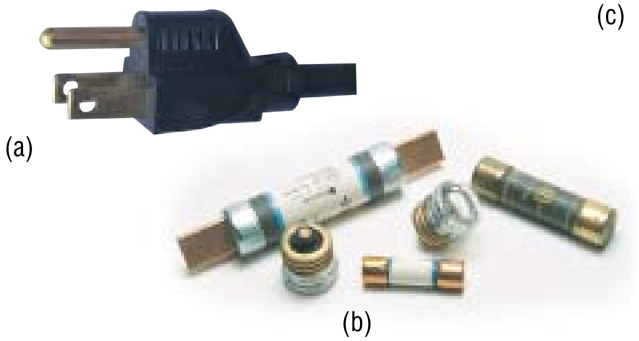
Electrical Safety Pointers

- Never handle electrical devices when you are wet or near water unless they are specially designed and approved for use in wet areas.
- Don't use any power cord that is frayed or broken.
- Always unplug electrical devices before looking inside or servicing them.
- Don't put anything into an electrical outlet other than proper plugs for electrical devices.
- Don't overload circuits by plugging in and operating too many devices.
- Stay away from power lines.
- Don't bypass safety features built into home wiring, appliances, and other electrical devices.
- When unplugging a device, pull on the plug, not on the electrical cord.
- Never remove the third prong from a three-prong plug.

Plugs, Fuses, and Breakers

The grounded three-prong plug in Figure 1.16(a) has an extra wire that connects the device to the ground wire of the building. As you can tell by its name, this wire leads to the ground. It provides another pathway for electricity, just in case there is a short circuit in the device. It's better to have electricity travel to the ground than through an unfortunate user!

The **fuses** in Figure 1.16(b) and the **circuit breakers** in Figure 1.16(c) interrupt a circuit when too much current is flowing through it. Fuses contain a thin piece of metal that is specially designed to melt if too much current passes through it. Most household circuit breakers also have a special wire that heats up if there is too much current. Instead of melting, the hot wire triggers a spring mechanism that turns off the switch inside the circuit breaker. As soon as the wire has cooled, the circuit breaker can be turned back on. Never turn a circuit breaker back on until you have fixed the problem that caused it to switch off.



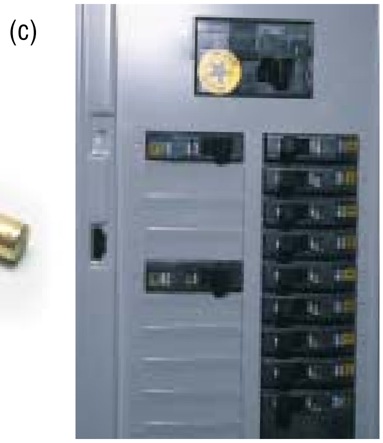


Figure 1.16 Three-prong plugs (a), fuses (b), and breakers (c) help prevent electric shocks and overloads.

*QUICK*LAB

Blow a Fuse!

Purpose

To observe the function of a fuse

Procedure

1. Connect the cell, switch, wires, and bulb as shown in Figure 1.17. Leave the switch open.
2. Remove a single strand from the steel wool. Clip the alligator clips onto the ends of the steel wool strand.
3. Close the switch and observe the bulb and the strand of steel wool carefully.

Questions

4. Explain your observations.
5. Why is a fuse a safety feature in a circuit? Use your observations to support your answer.

Materials & Equipment

- D-cell
- connecting wires with alligator clips
- switch
- 15-V bulb and holder
- steel wool

Figure 1.17 Set up your circuit like this one.

The Danger of Lightning

The current in a lightning strike can be as high as 30 000 A, so it's not surprising that it has the potential to kill. People can survive lightning strikes when the full amount of current travels through only part or over the surface of their bodies, but severe injury usually results. The best way to survive a lightning strike is to avoid getting hit in the first place. Lightning is a huge amount of negative charge and tends to seek the highest point on the horizon to discharge. Therefore, avoid standing on hilltops or under trees, or holding objects over your head (especially metal ones) if you are out in a thunderstorm.

Because tall buildings are a natural target for strikes, lightning rods are often added to their peaks. Lightning rods are connected to the ground with a wire. Instead of the lightning destroying the building's roof or electrical wiring, the discharge is conducted harmlessly to the ground.

Figure 1.18 The metal lightning rod on the roof is connected to the ground by a wire.

reSEARCH

Are Breakers Better?

All new houses have circuit-breaker panels instead of fuse panels. Are circuit breakers safer than fuses? Why do many commercial and industrial buildings still use fuses? Prepare a brief report comparing circuit breakers and fuses. Begin your information search at www.pearsoned.ca/scienceinaction.

Check and Reflect

Key Concept Review

1. What is more dangerous, current or voltage? Why?

2. What is the purpose of a fuse?

3. What is meant by a "ground wire"?

4. What is a short circuit?

Connect Your Understanding

5. A power line carrying a high current falls on a car, but the people inside are not electrocuted. Explain.

6. Are all electric shocks to the body dangerous? Explain.

7. Tall buildings often have a steel lightning rod that is connected to the ground with a wire. Lightning tends to strike these rods during storms. Why are these rods added and how do they work?

8. A friend has told you about plugging in a radio and putting it on the edge of the tub while taking a bath. Why is it unwise to listen to music this way?

9. Why is it a bad idea to take shelter under a tree in a thunderstorm?

Extend Your Understanding

10. You notice a friend removing the third prong of a plug so that the plug will fit into an extension cord that has only two holes. Is the removal of this third prong safe? Explain why or why not.

1.4 Cells and Batteries

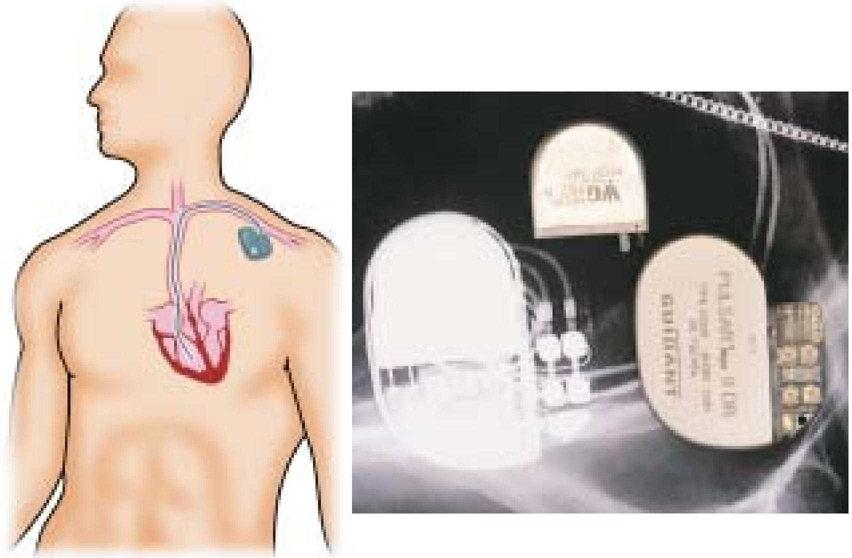
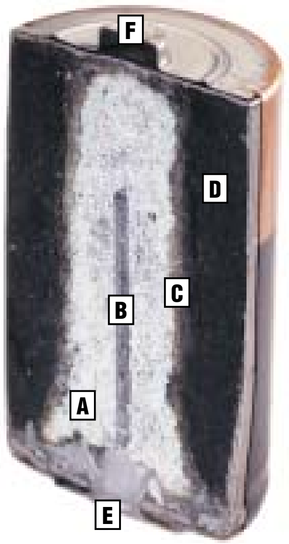


Figure 1.19 A pacemaker is inserted just under the skin, near the shoulder, and connected to the heart. An electrochemical cell supplies the electricity to keep the person's heart beating regularly.

Some people have problems with the small electrical signal that the body uses to control the beating of the heart. Doctors can implant a device called a pacemaker to help such people. The pacemaker delivers a small amount of current at regular intervals to keep the heart beating normally. The electricity used to operate a pacemaker comes from an **electrochemical cell** that supplies a steady current. An electrochemical cell is a package of chemicals designed to produce small amounts of electricity. The electricity the cell produces comes from chemical reactions. The tiny cells used in pacemakers are made with lithium and iodine and last from 5 to 12 years. Other cells, made with different chemicals, are used in devices ranging from toys to cars to computers. There are two main types of cells: dry cells and wet cells.



A – zinc powder and electrolyte, where electrons are released
B – electron collecting rod
C – separating fabric
D – manganese dioxide and carbon, where electrons are absorbed
E – negative terminal, where electrons leave
F – positive terminal, where electrons return

Figure 1.20 An alkaline dry cell

Dry Cells

The electricity-producing cells that we use every day in flashlights and portable radios are **dry cells**. They are called "dry" because the chemicals are in a paste. They are also sealed so they can be used in any position without the chemicals leaking out. Figure 1.20 shows an example of a typical alkaline dry cell, used in flashlights and other devices.

The chemical reaction in the cell releases free electrons. These electrons travel from the negative terminal of the cell, through the electricity-using device, and back to the positive terminal of the cell. While at first glance this cell may look complex, it is simply two different metals in an electrolyte. An **electrolyte** is a paste or liquid that conducts electricity because it contains chemicals that form ions. An **ion** is an atom or a group of atoms that has become electrically charged through the loss or gain of electrons from one atom to another. You can learn more about ions in Unit B: Matter and Chemical Change.

The electrolyte reacts with the two metals, called **electrodes**. As a result of this reaction, one electrode becomes positively charged, and the other becomes negatively charged. These electrodes are connected to the cell's terminals. In a dry cell, electrons leave from the negative electrode, and return to the positive electrode.

The cell shown in Figure 1.20 uses an alkaline electrolyte with zinc and manganese electrodes, but many other combinations of metals and electrolytes are possible. Alkaline cells have become the most common type of dry cell because they offer a good combination of cost, electricity output, shelf life, reliability, and leak resistance.

Wet Cells

Another type of electrochemical cell is shown in Figure 1.21. Such cells are known as **wet cells** because they *are* wet. A wet cell uses a liquid electrolyte that is usually an acid, such as sulfuric acid. Many of the earliest cells were wet cells, as are most cells in cars and trucks today. Wet cells are generally cheaper and easier to make than dry cells. However, care must be taken not to spill the liquid electrolyte, which may be highly corrosive.

Each electrode in the wet cell in Figure 1.21 reacts differently with the electrolyte. The acidic electrolyte gradually eats away the zinc electrode. This process leaves behind electrons that give the slowly disappearing electrode a negative charge. Eventually the zinc electrode must be replaced. The chemical reaction between the copper electrode and the acidic electrolyte leaves the copper with a positive charge, but does not eat away the copper. Electrons travel along the wire from the negative zinc electrode to the positive copper electrode. If you connected a wire from one electrode to a light bulb and another wire from the light to the other electrode, the bulb would light up. The electric current flowing from one electrode to the other provides the energy for the light. Car batteries like the one in Figure 1.22 are made up of wet cells.

info BIT

Plastic Cells

One of the drawbacks of cells is that they tend to be heavy and rigid. One solution to this is to make cells out of plastic. Normally plastic is an insulator, but substances can be added to make the plastic act like metal electrodes. While plastic cells are not yet as powerful as metal-based cells, they are very light and flexible. They can be made as thin as a credit card.

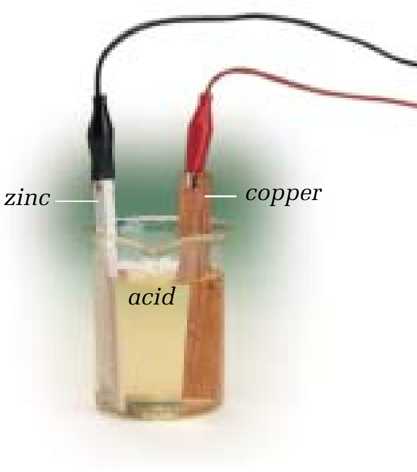


Figure 1.21 A simple wet cell includes two electrodes and a liquid electrolyte.

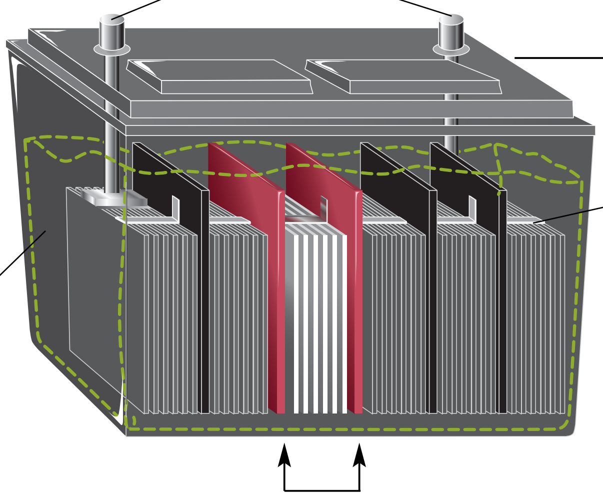


Figure 1.22 A car battery made up of six lead-acid wet cells. Each cell contains alternating positive and negative metal plates (electrodes) in a sulfuric acid electrolyte.

*QUICK***LAB**

FRUIT CELLS

Purpose

To test the ability of fruits and vegetables to act as electrolytes

Procedure

1. Choose one fruit or vegetable. Insert the two different electrodes into the fruit about 1 cm apart. Push them down to a depth of about 2 cm, making sure they remain about 1 cm apart.
2. Use the connecting wires to connect the electrodes to the voltmeter. Record the reading on the voltmeter scale.
3. Predict which fruit or vegetable will produce the largest voltage. Test your prediction by repeating steps 1 and 2 with the different fruits and vegetables.

Questions

4. What do you think would happen if you reversed the connections on the electrodes? Explain.
5. Would it be possible to use two or more fruits linked together to produce voltage? Draw a diagram of how you might accomplish this, and predict the voltage results. Test your prediction by connecting several fruits to a voltmeter.

Materials & Equipment

- straight pieces of copper wire (electrode)
- straightened paper clips (electrode)
- connecting wires
- voltmeter
- various fruits and vegetables (e.g., lemons, potatoes)

RECHARGEABLE CELLS

The dry cells and wet cells you have read about are called **primary cells**. Primary cells produce electricity from chemical reactions that cannot be reversed. However, the chemical reactions in a **rechargeable cell** can be reversed by using an external electrical source to run electricity back through the cell. The reversed flow of electrons restores the reactants that are used up when the cell produces electricity. We can say that the chemicals in a rechargeable cell store electricity supplied by the external source. Rechargeable cells are also known as **secondary cells**. They are used to start cars and to operate portable electronic devices such as notebook computers and cellular phones.

Not all reversible chemical reactions are suitable for use in rechargeable cells. The reverse reaction must occur efficiently, so that hundreds of recharging cycles are possible. Nickel oxide and cadmium is one combination of chemicals often used in secondary cells. You may have seen them advertised as Ni-Cd or Ni-Cad batteries. Applying electricity to the rechargeable cell reforms the original reactants. This process does not reform the electrodes perfectly, however, so even rechargeable cells wear out in time.

ACTIVITY D-2

Inquiry

CHOOSING ELECTROLYTES

The Question

What type of solution is the best electrolyte for a wet cell?

The Hypothesis

Form a hypothesis for this investigation based on the question. Use the terms "manipulated variable" and "responding variable" in your hypothesis.

Materials & Equipment

- two 500-mL beakers
- voltmeter or voltage sensor
- zinc and copper electrodes
- electrode clamps
- connecting wires
- distilled water for rinsing
- various liquids including distilled water, tap water, sugar solution, salt solution, lemon juice, vinegar, dilute hydrochloric acid of varying concentrations, dilute potassium hydroxide of varying concentrations, or other solutions provided by your teacher

Procedure

1. In your notebook, make a table for recording voltages for the different solutions.
2. Attach the clamps to the copper and zinc electrodes. Place the electrodes in the beaker, making sure they don't touch each other. Your set-up should resemble the one in Figure 1.23.
3. Use connecting wires to hook the electrodes up to the voltmeter. Connect the negative terminal of the voltmeter to the zinc electrode.
4. Fill the beaker with distilled water, so that the bottom halves of the electrodes are immersed. Note the level of the liquid or mark it on the beaker. Record the voltage.
5. Disconnect the electrodes and empty the beaker, then rinse them all with distilled water.
6. Set up the beaker and electrodes again, using a different solution. Fill the beaker to the level noted in step 4 with one of the solutions you want to test.
7. Repeat steps 4–6 until all the solutions have been tested. Each time, be sure to rinse the beaker and electrodes with distilled water before pouring in the next solution.
8. When you have finished testing the solutions, follow your teacher's instructions for disposing of them.

Figure 1.23 Testing electrolytes

Analyzing and Interpreting

9 Are all the liquids electrolytes? Why or why not?

10 Why do you think some substances are better electrolytes than others?

Forming Conclusions

11 Write a summary describing the type of solution that is the best electrolyte for a wet cell. Use your data to support your conclusion.

Applying and Connecting

Electrolytes are also found in the body in the form of many different dissolved ions, such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and chloride (Cl^-). These dissolved ions serve several functions in the body. One of the most important is to help establish voltages across the cell membranes of nerve cells. Resting nerve cells maintain an internal voltage of about –70 mV. When these cells are stimulated, Na^+ ions rush into them, changing the voltage briefly to about +35 mV. This momentary voltage change makes up the impulses that allow nerve cells to send messages all over the body.

Extending

A variety of substances can function as electrodes in cells. These include aluminum, iron, carbon, tin, lead, and nickel. Design and conduct an experiment that tests different pairs of electrodes to see which pairs produce the greatest voltage.

Figure 1.24 This 6-V battery is made up of four 1.5-V cells.

BATTERIES

You probably own electronic devices that require more than one dry cell. Connecting cells together creates a **battery**. Most batteries are sealed into cases with only two terminals, so many people don't realize that batteries contain more than one cell. For example, the rectangular battery in Figure 1.24 is a "true" battery because it contains four cells.

ELECTROCHEMISTRY

Alessandro Volta made the first practical battery around 1800. He piled many copper and zinc discs on top of each other, separating them with electrolyte-soaked paper discs. When scientists realized that connecting many cells together could produce more voltage and power, innovation soon followed. For example, in 1807, Humphry Davy, a professor in England, filled a whole room with 2000 cells to make one massive battery.

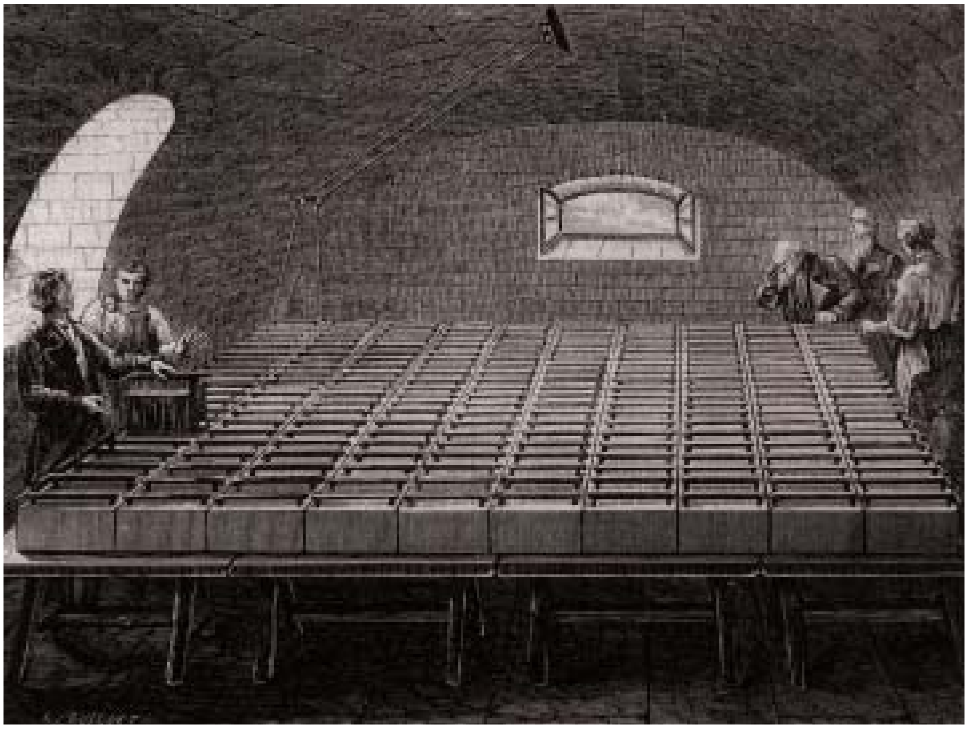


Figure 1.25 Humphry Davy connected 2000 cells together to form one battery.

Other scientists had earlier used smaller batteries to split molecules into their elements, a process called **electrolysis**. For example, they were able to split water into hydrogen and oxygen. Davy's battery was so powerful that he was able to separate pure metals out of molten compounds and ores. Using electrolysis, Davy discovered potassium, sodium, and other elements. The work of Davy and others led to a whole new field of science: **electrochemistry**, the study of chemical reactions involving electricity. Obtaining electricity from a chemical cell is just one of the many applications of electrochemistry. Electrolysis is another.

Electrolysis

Many industrial processes use electrolysis to separate useful elements from solutions. For example, chlorine produced by electrolysis is used to make drinking water safe. It is also used to produce polyvinyl chloride (PVC) products such as pipe and wire insulation.

Electrolysis of water produces the fuel for the space shuttle. The water molecules are separated into pure hydrogen and oxygen. When these two gases are mixed and ignited, they release a tremendous amount of energy, making these two elements a powerful rocket fuel.

Figure 1.26 These PVC pipes and the PVC insulation on these wires are made with chlorine produced by electrolysis.

Figure 1.27 Electrolysis produces rocket fuel by separating water molecules into the elements hydrogen and oxygen.

Electroplating

Metals such as silver and gold are popular for use in jewelry and other decorative items, but they are expensive. Less expensive products can be made by coating a cheaper metal with a thin layer of silver or gold. This process is called **electroplating**. The cheaper metal is also usually stronger than pure silver or gold. The spoon in Figure 1.28 was silver-plated.

Figure 1.29 shows how electroplating is done. The item to be coated and a bar of the coating metal are immersed in an electrolyte, like the electrodes in a wet cell. A source of electricity is connected between the two metals. The flow of electricity through the electrolyte deposits atoms from the positively charged metal onto the negatively charged one. Electroplating is often used to protect metals from corrosion. For example, a plating of chromium or nickel can protect iron or steel from rusting.

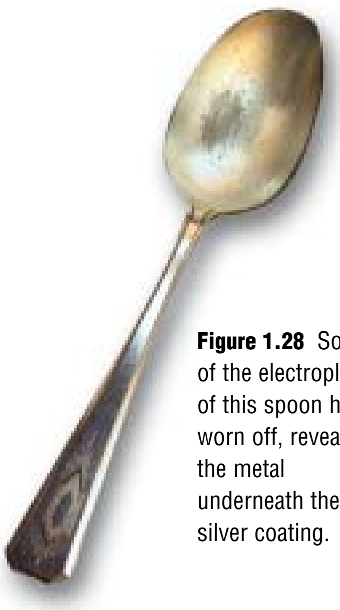


Figure 1.28 Some of the electroplating of this spoon has worn off, revealing the metal underneath the silver coating.

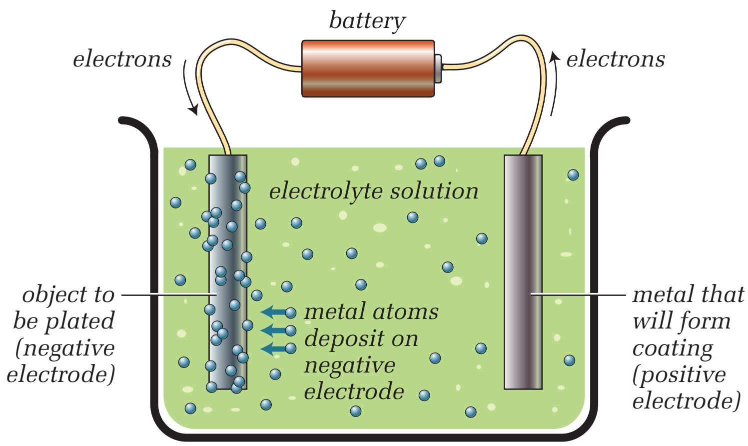


Figure 1.29 The process of electroplating. Different metals can be electroplated by using different electrodes and electrolytes.

reSEARCH

Galvanizing

Galvanizing is the process of applying a coating of zinc onto metals such as iron or steel. Using books or electronic resources, prepare a brief report about the advantages and disadvantages of galvanizing. Begin your search at www.pearsoned.ca/scienceinaction.

Other Electrochemical Applications

Anodizing and electrorefining are two more examples of electrochemical processes used in Canada. Anodizing is a process to coat aluminum parts with a layer of aluminum oxide. This oxide coating is much harder than pure aluminum. Anodizing is used on a wide range of products including aluminum screen doors, airplane or car parts, kitchenware, and jewellery.

Electrorefining can be used to remove impurities from metal. For example, impure gold can be formed into bars that serve as an electrode in an electrolytic cell. The impure bars are put into a strong acid solution (the electrolyte), along with a thin strip of pure gold. When current is applied, it moves from one electrode to the other. At the same time, pure gold dissolves from the impure electrode into the acid electrolyte. The dissolved pure gold moves to the electrode made out of pure gold and is deposited there. The other impurities and unwanted metals are left behind in the electrolyte. This process produces very pure gold.

In another application of electrochemistry, some automobile companies use an electrochemical process to bond special paints onto car parts.

Check and Reflect

Key Concept Review

1. What is electrolysis? Give one example of an application of electrolysis.
2. What is an electrolyte?
3. What was Alessandro Volta's contribution to battery technology?
4. How does a rechargeable cell work?

Connect Your Understanding

5. Which would be a more practical source of electricity for a car: a wet cell or a dry cell? Why?
6. Describe the components of a wet cell and explain how the cell produces electricity. Use a diagram in your answer.
7. Dry cells are designed to keep electrons flowing. Why do they eventually "die" (stop working)?
8. Draw a diagram of an electroplating apparatus that would coat copper with gold. Be sure to label all parts of your apparatus.

Extend Your Understanding

9. Figure 1.30 shows an older design for a dry cell, which is still widely used. How does this design differ from the alkaline cell shown in Figure 1.20 on page 288?
10. A car designer has proposed a new car battery. She is planning to test the following different electrode combinations:
    a) both zinc c) both copper e) both carbon
    b) zinc and copper d) zinc and carbon
    Will all of these combinations work? Explain why or why not.

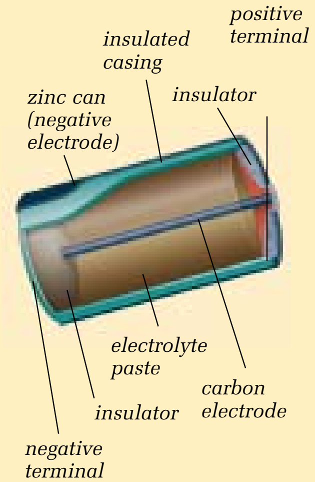
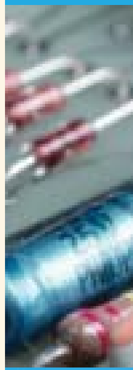


Figure 1.30 Question 9—older design for dry cell

SECTION REVIEW



Assess Your Learning

Key Concept Review

1. Describe the charged particles in an atom.
2. What are electrodes? Explain their role in a dry cell.
3. What is the difference between a cell and a battery?
4. State three guidelines for electrical safety.

Connect Your Understanding

5. Describe how a static charge might build up on you as you walk across a carpet.
6. Some cells are rechargeable. Others must be discarded when they run out of energy. Explain the difference between these two cell types.
7. Fuses are designed to interrupt the flow of current. Why are they included in a circuit?
8. Lightning is a dangerous discharge of electrons built up by friction between air and water molecules in a cloud. Is this discharge current electricity or static electricity? Explain the reason for your choice.
9. Static discharges are classified as electricity, but cannot provide the energy to operate your household devices. Why?

Extend Your Understanding

10. Computer circuits can be damaged by static discharges. To prevent this, technicians usually wear an anti-static strap that is connected to the metal case of the computer. Explain how wearing such a strap protects computer circuits.
11. A tall tree stands in a yard, towering over a one-storey house. There are no other trees in the area. A car is parked on the street. Which object is most likely to be struck by lightning: the tree, the house, or the car? Explain your answer.

Focus On SCIENCE AND TECHNOLOGY

Scientific knowledge may lead to the development of new technologies. And new technologies may lead to scientific discovery. Think about what you learned and the activities you did in this section.

1. Describe one example from this section of how scientific knowledge led to a new technology, which then led to scientific discoveries.
2. What would someone who wanted to invent a new type of electrical cell need to know about electricity?
3. Describe one example of an electrical technology that is used in scientific research today.

2.0 Technologies can be used to transfer and control electrical energy.

Key Concepts

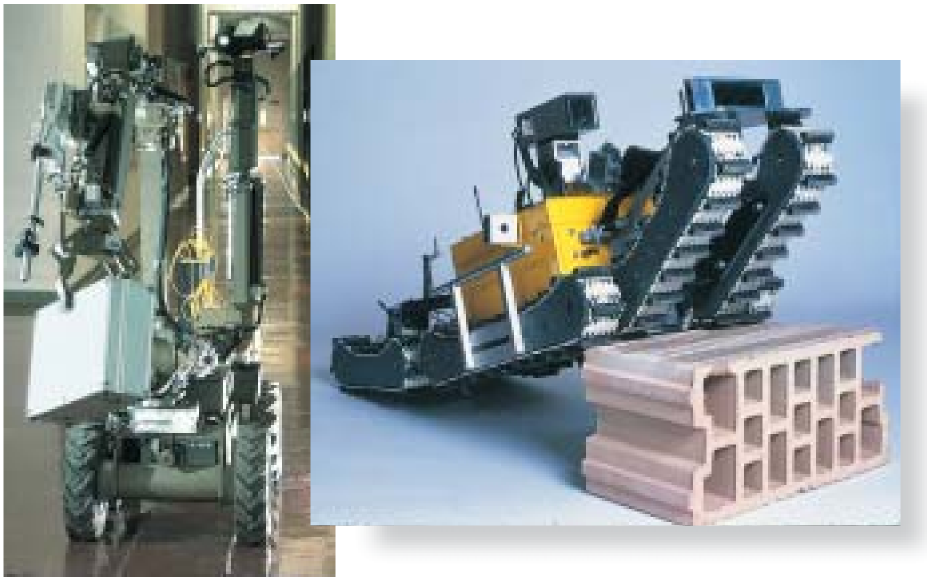
In this section, you will learn about the following key concepts:

- electric current
- circuits
- energy transmission
- measures and units of electrical energy
- electrical resistance and Ohm's law

Learning Outcomes

When you have completed this section, you will be able to:

- identify electrical conductors and resistors
- compare the resistance of different materials
- use switches and resistors to control current
- predict the effects of switches, resistors, and other devices
- use models to describe and relate electrical current, resistance, and voltage
- measure voltages and amperages in circuits
- calculate resistance using Ohm's law
- develop, test, and troubleshoot circuit designs
- draw circuit diagrams for toys, models, and household appliances
- compare and contrast micro-electronic circuits and circuits in a house



Specially equipped remote-control (RC) vehicles like the ones in these photos protect people from risky situations. Robotic video crawlers can be sent into dangerous or hard-to-reach places to provide remote "eyes" for experts. Bomb disposal robots can help with inspection, removal, and disposal of suspicious packages. These sophisticated RC vehicles can do a variety of difficult and dangerous tasks. They are powered with electric current and controlled with the help of special circuits.

When you manipulate the controls of an RC vehicle, it moves and turns. But behind these seemingly simple actions are devices that control the flow of electric current. A small battery in the transmitter unit that you hold provides current that allows the antenna to produce radio waves. These radio waves travel through the air and induce a current in the antenna on the RC vehicle. This antenna is connected to circuits. The circuits control current through wiring that leads to the battery-powered motors inside the vehicle. These control speed, turning, direction, and other special equipment such as limbs and video cameras.

The transfer and control of electrical energy in an RC vehicle is one example of the application of electrical technologies. In this section, you will learn about technologies for controlling electricity, how to measure electricity, and how to analyze and build electric circuits.

For Web links relating to 2.0, visit **www.pearsoned.ca/scienceinaction**

2.1 Controlling the Flow of Electrical Current

Figure 2.1 The controlled use of electricity creates a colourful neon display.

A neon sign has several interesting applications of electrical technology. First, electricity must travel all the way through the tube in order to make the neon gas inside glow. Second, the sign must be equipped with a control so it can be turned on and off. Third, the whole thing must be contained so that people nearby aren't accidentally electrocuted. These tasks can all be done by controlling the flow of electric current.

A Unique Circuit

Neon signs usually consist of a glass tube, twisted into the desired shape. The tube is filled with gas and metal terminals are sealed into the ends. The metal terminals of the tube are then connected to the positive and negative terminals of the electrical source. So the sign is a circuit, but unlike the wire circuits you saw earlier, this circuit includes a gas as a conductor.

Signs with more complex designs may have several different tubes, each with its own electrical connectors. These tubes may have special coatings or contain different gases that produce different colours. A mixture of neon and argon provides a purple light. Helium provides yellowish-white light.

Usually, neon gas is an insulator—it does not conduct electricity. But when current is applied to the tube, electrons in the neon atoms are "excited" by the added energy, and free themselves from the atoms. The negative electrons leave behind positive neon ions. This creates a mixture of charged particles inside the tube, which is excellent at conducting current. As the current continues to add energy to the neon gas, some of the electrons "fall" back into the neon ions, releasing their energy as the orange-pink neon light we see in the sign.

*info***BIT**

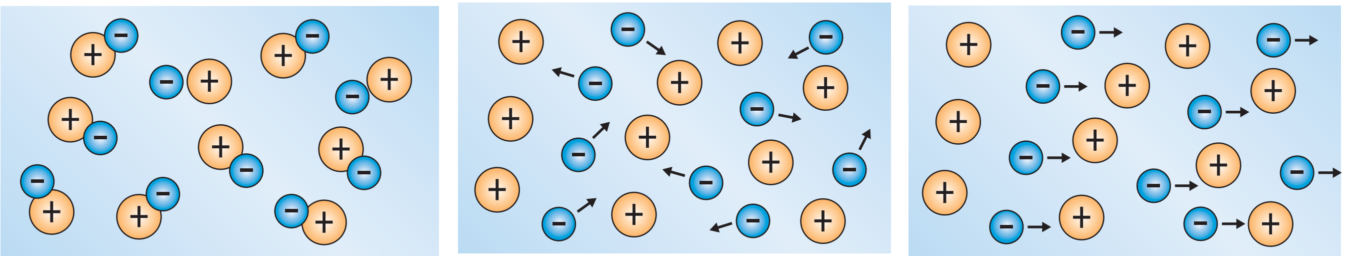
Semiconductors

Labelling a substance a conductor or insulator isn't always easy. Some substances, such as glass and rubber, make excellent insulators—they don't conduct at all. Many metals, such as copper and iron, are excellent conductors. Semiconductors are somewhere in between. Germanium and silicon are two commonly used semiconductor elements. At high temperatures, they act like conductors. At low temperatures, they act like insulators.

Conductors and Insulators

As shown in Figure 2.2, electrons in insulators are tightly bound to the positive nucleus of their atoms. They resist moving away from the nucleus. In conductors, the electrons are not as tightly bound. They are freer to move. However, a current will flow only when the conductor is connected to an electrical source. The electrons then move toward the positive end of the voltage source. Another way of saying this is that the electrons move when a voltage is applied.

Figure 2.2 is a simplification to help you see how electrons generally behave in insulators and conductors. However, the atomic structure of a substance affects how well it conducts or insulates. In other words, some substances are more resistant to electron flow than others. Depending on how you want to control current, you may choose to use a substance that is an insulator, conductor, or partial conductor.



(a) Insulator: The electrons (–) are bound tightly to the nuclei (+) so they resist movement.

(b) Conductor with no voltage applied: The electrons are not as tightly bound to the nuclei. They can drift away from the nuclei but do not flow in any one direction.

(c) Conductor with voltage applied: The electrons flow toward the positive terminal of the voltage source.

Figure 2.2 Electrons in a conductor are free to move, while those in an insulator are not.

Superconductors

Metals such as silver, copper, mercury, and gold are all excellent conductors, but they are not perfect conductors. Electrons travelling through them encounter some resistance. This resistance varies from metal to metal, which is why one metal is a better conductor than another. However, it is possible for metals to superconduct. **Superconductors** are perfect conductors—they have no resistance to electron flow. Superconductivity was discovered by Dutch physicist Heike Kamerlingh Onnes in 1911 when he brought the temperature of mercury down to near absolute zero (−273°C) using liquid helium. At this temperature, Onnes found that mercury was a perfect conductor, with no resistance to current flow. Since that time, substances have been found to superconduct at temperatures well above absolute zero. But these temperatures are still too low for practical applications. Research into superconductivity continues.

ACTIVITY D-3

Inquiry

INVESTIGATING CONDUCTIVITY

Materials & Equipment

- 100-mL graduated cylinder
- 250-mL beaker
- distilled water
- conductivity tester
- tap water
- salt water
- vinegar
- copper(II) sulfate solution
- other solutions provided by your teacher

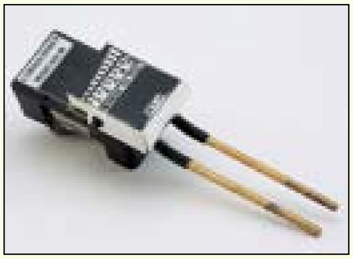


Figure 2.3 A conductivity tester

The Question

How does the conductivity of different solutions compare?

The Hypothesis

Reword the question to form a hypothesis.

Procedure

1. Design a table to record the conductivity readings of the solutions you will test.
2. Put 50 mL of distilled water into a 250-mL beaker.
3. Place the metal tips of your conductivity tester in the distilled water.
4. Record the conductivity reading of the distilled water in your table. If your conductivity tester is a light bulb, describe the brightness of the bulb.
5. Repeat steps 2–4 with 50-mL samples of tap water, salt water, vinegar, copper(II) sulfate solution, and any other solution you wish to test. After each conductivity measurement, empty the beaker and rinse it with distilled water. Also wipe off the tips of the conductivity tester. Make sure that you insert them to the same depth in each solution.
6. When you have finished testing the solutions, follow your teacher's instructions for disposing of them.

Analyzing and Interpreting

7. Were there differences in conductivity among the solutions you tested? How could you tell?
8. Account for the differences in conductivity among the solutions by explaining what is happening in the solutions.

Forming Conclusions

9. Write a summary of your results that answers the question: How does the conductivity of different solutions compare?

Applying and Connecting

Solution conductivity is a powerful tool for studying the environment. Electrical conductivity (EC) increases with the number of ions dissolved in water. This means that conductivity readings can be used as indicators of water quality and the composition of the surrounding soil. Higher EC values in water can be natural because of minerals dissolved in the water; for example, in lakes that have limestone basins. But higher EC levels can also signal the presence of pollutants in a watershed because pollutants are a source of additional ions. An example is the use of salt on roads as a safety measure to remove ice. Unfortunately when the snow and ice melt, large amounts of salty run-off water enter lakes and streams and can be harmful to aquatic organisms. EC readings can be used to monitor the concentration of salt and other pollutants in the water.

Extending

Design and conduct an experiment to investigate the relationship between the amount of a dissolved solute (such as salt) and electrical conductivity.

Using Conductors, Resistors, and Insulators

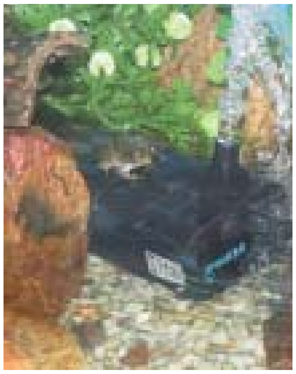


Figure 2.4 This pump is sealed in waterproof rubber and plastic.

Engineers need to know how well different materials conduct electricity so they can design devices that are both effective and safe. For example, sometimes electricity must be used around water. This is dangerous unless all the current-carrying wires are carefully insulated and sealed from the surroundings.

In some applications, a type of conductor called a **resistor** is useful. A resistor allows electric current to pass, but provides resistance to it. This limits the amount of current. For any given voltage, more current flows through a resistor with a low resistance than through one with a high resistance. **Resistance** is a measure of how difficult it is for electrons to flow through a substance. It is measured in **ohms**. The symbol for ohm is Ω, the Greek letter omega.

The more resistance a substance has, the more the substance gains energy from each electron that passes through it. The energy gained by the substance is radiated to its surroundings as either heat or light energy.

Figure 2.5 shows two examples of metal resistors that produce heat and light.

Figure 2.5 The tungsten filament in an incandescent bulb and the element in a heater both radiate heat and light because of resistance.

Solutions can also be resistors. The more charged particles in a solution, the better it conducts. Distilled water is not a good conductor because it contains only water molecules. These molecules have no electrical charge. Tap water and water in the environment are conductors because of the many dissolved minerals they contain. Knowing the conductivity of a particular solution can be of practical use. For example, you could use a simple conductivity measurement to check the purity of a batch of distilled water. In a factory, a technician may use conductivity to check whether a solution for an industrial process has been mixed properly.

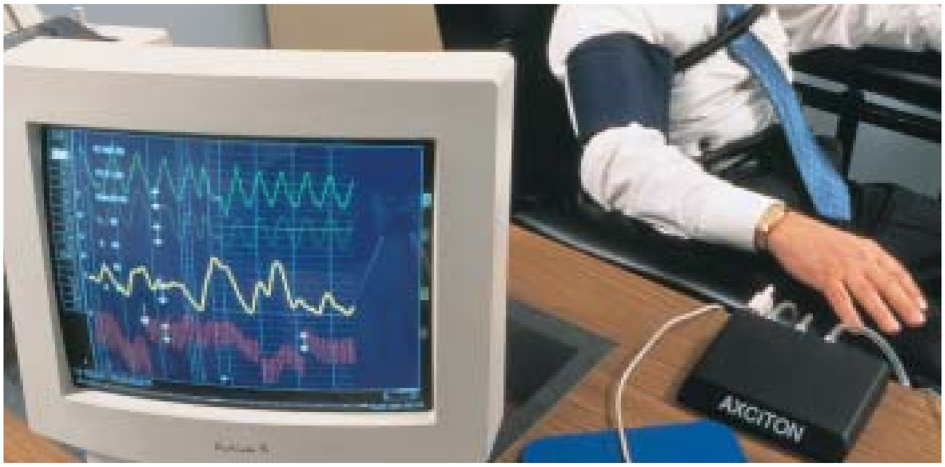


Figure 2.6 A person taking a polygraph test

The polygraph machine or "lie detector" is another application of resistance. It usually measures skin resistance, blood pressure, and respiration. All of these change when people are under stress. Sweat is mostly a salt solution, so it contributes to the change in skin resistance. To measure this change, two or more metal electrodes are attached to the skin of the person taking the test. In theory, the person is under the most stress when lying in response to a question. Thus, a lie should cause an increase in conduction between the electrodes. This would show up as a peak on the graph plotted by the polygraph machine.

math Link

The more resistance a component has, the lower its conductivity, and vice versa. Resistivity (R) and conductivity (G) are inversely related. The equation for this relationship is $R = 1/G$.

If chemicals are added to a sample of solution so that its conductivity doubles, what happens to its resistivity? How does the conductivity change if the sample is diluted so much that its resistivity quadruples?

QUICKLAB

MAKE YOUR OWN DIMMER SWITCH

Purpose

To control the amount of current flowing through an electrical device

Procedure

1. Connect all the materials to form a big loop, as shown in Figure 2.7.
2. Make sure the Nichrome wire is connected by the ends, making all of the wire part of the circuit. Note the brightness of the bulb.
3. Now move the alligator clips on the Nichrome wire closer together, so that only a small amount of the Nichrome wire is part of the circuit. Note the brightness of the bulb.
4. Continue to observe the bulb as you slide one of the alligator clips back and forth on the Nichrome wire.

Question

5. What happened to the brightness of the bulb when you moved the alligator clips? Explain your observations.

Materials & Equipment

- battery
- connecting wires
- bulb and socket
- about 40 cm of 32-gauge Nichrome wire
- board with screws (optional)

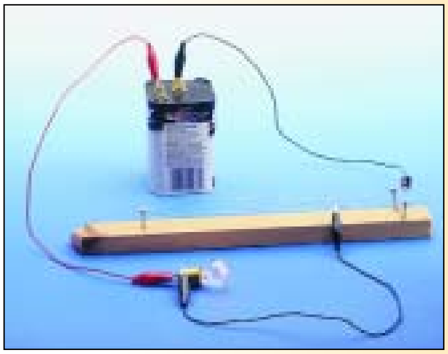


Figure 2.7 Apparatus for controlling current

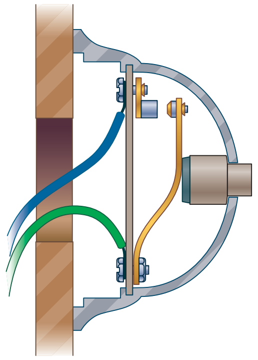


Figure 2.8 This doorbell button is an example of a momentary switch. As soon as you release the button, the contact arm springs back and opens the switch. The switch is closed only for a moment.

Switches and Variable Resistors

A switch is usually the best method for turning electricity on and off in a circuit. Although there are thousands of kinds of switches, they all work on the same basic principle. Look at Figure 2.9. When a switch is on, two conductors are pressed together so that current can flow from one to the other. When the switch is off, the conductors are separated and no current flows. Most switches are enclosed in an insulated casing or a metal box to prevent shocks and short circuits. The casing also keeps dust and other contaminants out of the switch mechanism.

Sometimes you want to change the current flow gradually in a circuit, rather than just turning it on or off. For example, you may have a light switch in your house that's used to dim the lights. This type of control device is called a **variable resistor** or **rheostat**.

Rheostats can increase or decrease the amount of current in a circuit by adjusting the portion of the resistor that the current travels through. Examples of rheostats are volume controls on stereos and foot-operated speed controls for sewing machines. As you turn the knob or press the pedal, you change the amount of current flowing through the circuit.

reSEARCH

Discovering Electricity

Michael Faraday, Luigi Galvani, and Joseph Henry all made major contributions to the science of electricity. Write a brief profile of each person, describing his life and work. Begin your information search at www.pearsoned.ca/scienceinaction.

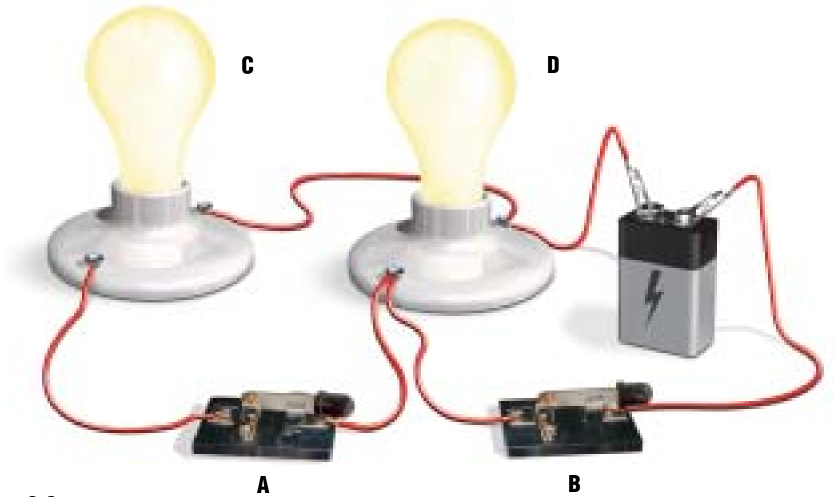
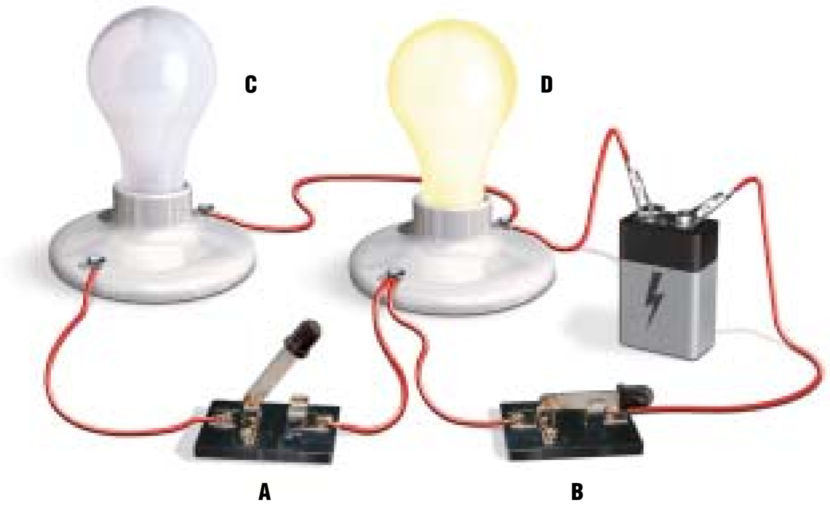


Figure 2.9
(a) Both switches are closed, so the current flows through both bulbs.



(b) Switch A is open, so the current cannot flow through bulb C.

Check and Reflect

Key Concept Review

1. What is the difference between a conductor and an insulator?
2. What is a resistor?
3. How does a switch control current flow?
4. How might a polygraph machine indicate someone is lying?

Connect Your Understanding

5. Why do some substances conduct while others do not?
6. Use a labelled diagram to explain how electrons behave in a conductor when:
   a) no voltage is applied
   b) voltage is applied
7. You have two wires made of two different metals (metal A and metal B). Both wires are the same thickness and length. In one circuit, you use the metal A wire. In another identical circuit, you use the metal B wire. The metal A wire gets hot, while the metal B wire does not. Explain.
8. A friend insists that using an electric drill in his flooded basement is safe because, he says, "Water doesn't conduct electricity." What would you say to your friend?

Extend Your Understanding

9. You have built a fountain for your backyard pond. How might you control the pump speed so that the water doesn't spray too high or too low?
10. Wood burning is a popular hobby. Would a wood-buring tool work well if its heating element had a very high resistance? Explain your answer.

Figure 2.10 Wood burning

Careers and Profiles

Computer Network Technician

A computer network technician helps computers communicate. This job involves dealing with many computers, electronics systems, and wires.

A computer network technician must have a good understanding of switches and wiring. You have to run new wires to connect computers to the network, and you have to understand computer operating systems in order to configure computers to the network properly. You have to be a good troubleshooter in order to find components that are malfunctioning in a network. Your job might include maintaining the computers and wiring for a local area network (LAN) in an office. In critical networks, you also maintain redundant systems. These are special computers that can run the network if the main computer fails.

Figure 2.11 Computer network technician at work

1. How does this job affect how much work other people do?
2. What kind of training would you need to be a computer network technician? Is this the type of career that would sometimes require extra training? Why or why not?
3. Does a computer network technician sound like an interesting career? Why or why not?

*info***BIT**

Another Measure of Electricity

Electrical charge is measured in coulombs, named after the French scientist Charles A. Coulomb. In the late 1700s, Coulomb measured the electrical force that charged objects exerted on each other. One coulomb is a large amount of charge—it equals 6.25 billion billion electrons.

2.2 Modelling and Measuring Electricity

So far in this section, you have learned many different terms to describe electrical current. Voltage, current, resistance, conductors, and cells all describe different aspects of electron flow. But all these terms can be confusing. Since electrons "flow" through conductors and resistors, a model using water can be helpful for understanding electricity.

Like flowing water, electricity must come from a source. Like water smashing into rocks in rapids, electricity encounters resistance. The more water, the more powerful the current in a river. The more electrons, the more powerful the current is in a conductor.

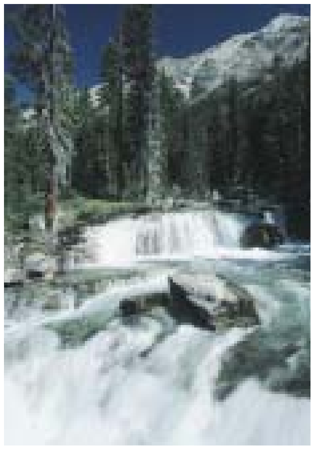


Figure 2.12 The flow of this Rocky Mountain stream is like the flow of electricity.

For both water and electricity, the source must be constantly replenished for flow to continue. Through the water cycle, snow is deposited on the mountain in Figure 2.12. The melting snow keeps the stream flowing. For electricity, a source such as a generator or cell keeps the electricity flowing from a negatively charged terminal to a positively charged one.

If the snow all melted away, the water flow would stop. If the generator is shut down or when the cell is used up, the electricity stops flowing.

***QUICK*LAB**

Funnel Power

Purpose

To build a model that represents different amounts of current and resistance in a circuit

Materials & Equipment

- 2 funnels with different-size drain holes
- 2 equal lengths of tubing of different diameters to fit on the two funnels
- beaker
- water
- ring stand
- timer

Procedure

1. Set up the ring stand, beaker, tubing, and the smaller funnel as shown in the cartoon.
2. Have your partner start the timer as you start to pour 150 mL of water into the funnel quickly and smoothly. When all the water is in the beaker, stop the timer. Record the time.
3. Repeat step 2 with the larger funnel and tubing. Record the time.

Question

4. Explain how your results can serve as a model of current and resistance.

Modelling Voltage

Unless there is a change in elevation, water doesn't flow—it simply sits in a pool. If you pump water up a hill, it gains gravitational potential energy, and then flows back down. In a similar way, a cell, battery, or generator "pumps" electrons to a point with a higher electric potential (voltage). Electricity will not flow without a difference in electrical potential, just as water does not flow without a difference in gravitational potential energy.

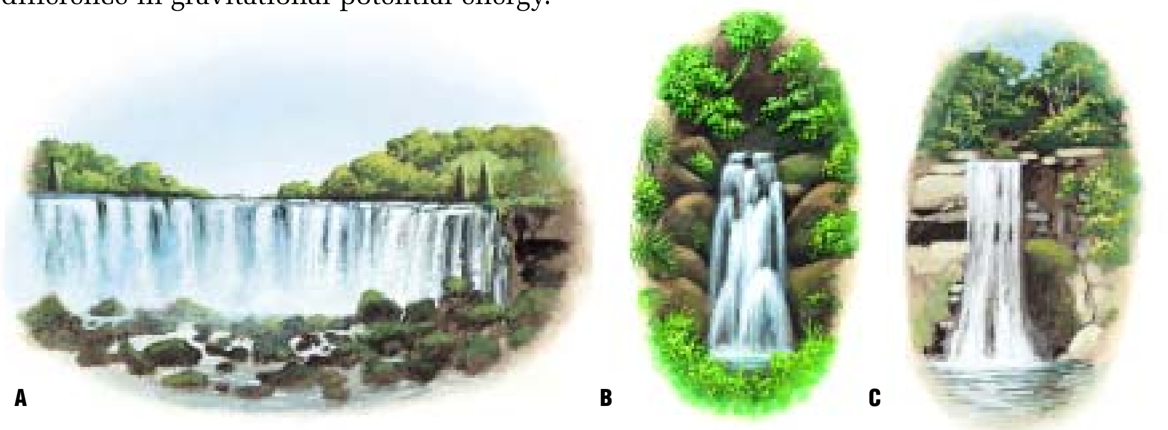


Figure 2.13 Waterfalls can model current, voltage, and resistance in a circuit. Waterfall A has a large flow of water. Waterfalls B and C are the same height, but B has more rocks that slow the flow. As an electrical circuit, waterfall A would have the greatest flow of current. Waterfalls B and C would have similar voltages, but B has greater resistance, and therefore less current flow.

The water in a garden fountain might be only a metre from the ground, while the water in a town's water tower might be 50 metres from the ground. The water from the water tower has much more gravitational potential energy and flows to the ground with greater force. Similarly, the high-voltage electrons from a generating station have more electrical potential energy than low-voltage electrons from a flashlight battery.

Modelling Resistance and Current

The flow of water in pipes is another useful model of electricity. Suppose you were using a reservoir to provide irrigation water for a field. You have to decide what size of pipes to use to drain the reservoir. A pipe with a small diameter might be easier to hook up. However, the longer and thinner a pipe is, the more resistance it has to the flow of water. A pipe with a bigger diameter has less resistance, which allows a greater flow of water.

Similarly, the amount of resistance in a circuit affects the electrical current. For any given voltage, current decreases if you add resistance. As with water flow, you get the least resistance with a short, wide path with no obstructions. The shorter and thicker the wire, the less resistance it creates for electrons. The flow of current will be reduced if it has to pass through a resistor.

Figure 2.14 Resistance in a stream or pipe reduces the flow of water.

Ohm's Law

Figure 2.15 Georg Simon Ohm

German scientist Georg Simon Ohm made exciting electrical discoveries in the early 1800s. He experimented with many different substances, and in 1826, he was able to prove a mathematical link between voltage (V), current (I), and resistance (R). The unit of resistance, the ohm, was named in his honour. **Ohm's law** states that as long as temperature stays the same:

- the resistance of a conductor stays constant, and
- the current is directly proportional to the voltage applied.

In other words, if you increase the voltage in a circuit, the current also increases.

Ohm's law also covers changes in resistance. If the voltage stays the same, but a resistor of greater value is used, then the current decreases. This table shows how to use Ohm's law.

Ohm's Law

Quantity	Symbol	Unit	Calculated with Ohm's Law	Measured with
Voltage	V	volts (V)	$V = I \times R$	voltmeter
Current	I	amperes (A)	$I = \frac{V}{R}$	ammeter
Resistance	R	ohms (Ω)	$R = \frac{V}{I}$	ohmmeter

math Link

In a circuit where voltage is kept constant, what happens to current if resistance is doubled? Quadrupled?

Applying Ohm's Law

The simple math of Ohm's law is a powerful tool for those who design or analyze circuits. As long as two of the values are known, the third one can be calculated. This means it is possible to calculate the value of an unknown resistor, or figure out the value of resistor needed to obtain a particular current.

Example

An electric stove is connected to a 240-V outlet. If the current flowing through the stove is 20 A, what is the resistance of the heating element?

Steps to Solving the Problem	Information and Solution
1. Identify known quantities.	current (I) = 20 A, voltage (V) = 240 V
2. Identify the unknown quantity.	resistance (R)
3. Use the correct formula.	$R = \frac{V}{I}$
4. Solve the problem.	$R = \frac{V}{I} = \frac{240\ \text{V}}{20\ \text{A}}$ $\boldsymbol{R = 12\ \Omega}$

While Ohm's law is a good tool for circuit analysis, it's not perfect. If the temperature of a resistor changes, its resistance changes as well. Generally, resistance is lowest when a conductor is cool. As the temperature increases, resistance increases. For example, a filament in a light bulb often has 10 times its normal current flowing through it at the instant it is switched on. This current heats the filament white hot in a fraction of a second. The huge rise in temperature greatly increases the filament's resistance, which reduces the current flowing through it. As explained in subsection 2.1, this increase in resistance causes the filament to glow. Light bulbs sometimes "blow" when they are switched on because of the sudden temperature change and other forces caused by the large initial current.

***SKILL* PRACTICE**

Using Ohm's Law

1. A 30-V battery creates a current through a 15-Ω resistor. How much current is created?
2. A motor has an internal resistance of 40 Ω. The motor is in a circuit with a current of 4.0 A. What is the voltage?
3. A current of 625 mA runs through a bulb that is connected to 120 V. What is the resistance of the bulb?

Using Test Meters

In subsection 1.2, you learned how a voltmeter is used to measure voltage. The voltmeter is just one of various types of meters used to measure electricity in a circuit. These devices use a small amount of current to move a needle across a specially calibrated scale or to display numbers on a digital readout. Meters are very useful, but they must be used properly to get accurate readings and avoid damage to their sensitive mechanisms.

Voltmeters

Recall that voltage is the potential *difference* between two points. To measure the potential difference across a cell, battery, resistor, or other device in a circuit, each terminal of the device must be connected to the appropriate positive or negative terminal of a voltmeter. Many electricians refer to the potential difference across a resistor or device as **voltage drop**. Note that meters used to measure small voltages are sometimes called **millivoltmeters**.

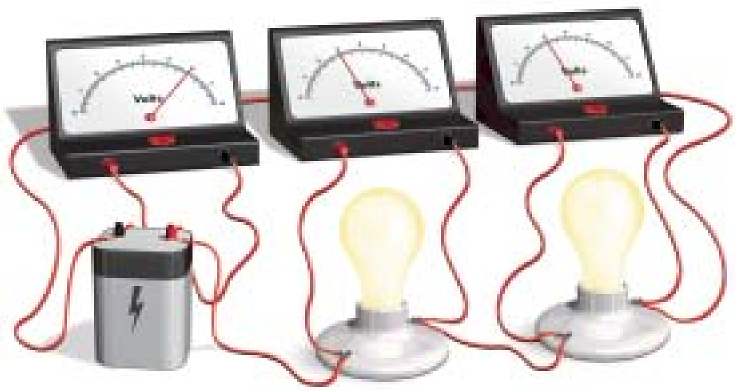


Figure 2.16 These voltmeters read the voltage difference across the items in this circuit.

Ammeters

Ammeters are used to measure electric current in amperes. Recall that current is the *rate of flow* of electricity in a circuit. It is a measure of how many electrons move past a point in a circuit each second. To measure this flow, an ammeter must be placed so that the current flows through it.

If a circuit consists of only one continuous loop, you can insert the ammeter between any two circuit components. Figure 2.17 shows an ammeter connected in a simple circuit. It could be attached at another place in the circuit and would still show the same reading. The current is the same at every point in the loop, so the ammeter can measure it anywhere. Meters used to measure small currents are sometimes called **galvanometers**.

SKILL PRACTICE

Using Ammeters

Connect a battery, light bulb, and ammeter in a loop as shown in Figure 2.17. Record the reading on the ammeter. Now add another bulb to the loop. Record that ammeter reading. Repeat this until you run out of bulbs. Explain your observations.

Suppose you repeated this activity with two electrical cells connected end to end (positive to negative). Predict what the ammeter readings would be. Explain your answer. Repeat the experiment to see if your prediction is correct.

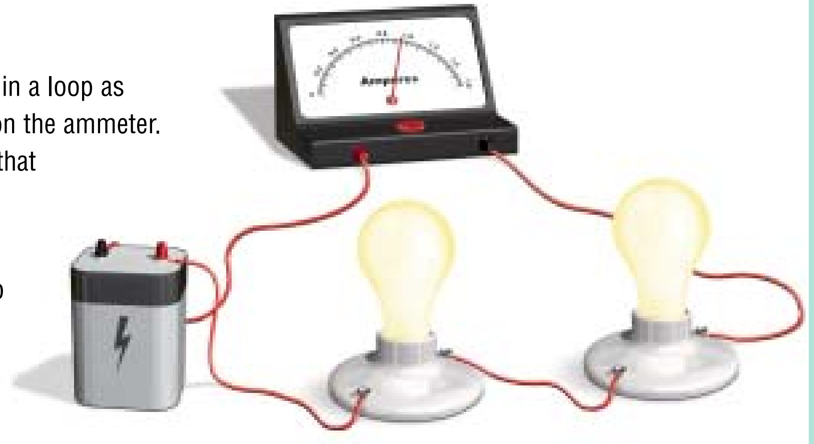


Figure 2.17 This ammeter will read the current for the circuit. The circuit shown has only one pathway, so the current is the same everywhere in the circuit.

Multimeters

Figure 2.18 Multimeters can be used to measure voltage, current, or resistance.

Often, meters are made with several different measuring circuits mounted in the same case. By turning a selector switch on the front of the case, you can set such **multimeters** to measure voltage, current, or resistance in a circuit. You must be careful that you have selected the right setting for the quantity you want to measure.

When you read a multimeter with a needle display, you must first find the scale that corresponds to the setting on the multimeter's selector switch. If the needle falls between numbers on this scale, you can estimate the last digit of your reading. For example, if the needle rests between 2 and 3 volts on the scale, but is slightly closer to the 2, you may estimate the reading as 2.4 volts. Digital displays do not require estimates. Some digital meters even allow you to select the level of precision (how many digits are displayed). Meters range from extremely precise instruments to simple, inexpensive testers that are accurate to only ± 5% of a full-scale reading.

ACTIVITY D-4

Inquiry

WHAT'S THE RESISTANCE?

The Question

Do different materials have different values of electrical resistance?

Materials & Equipment

- D-cell and holder
- 10-cm length of copper wire
- 10-cm length of Nichrome wire
- 10-cm length of solid graphite (pencil lead)
- 10-cm length of rubber tubing
- optional: 10-cm lengths of various other materials
- connecting wires
- voltmeter
- ammeter or current sensor
- ruler
- calculator

Caution!
The wires may get hot.

Procedure

1. In your notebook, set up a table for recording your data. The table should include the following headings: Substance, Length connected (10 cm or 1 cm), Voltage (from step 2), Current, and Resistance. In the "Resistance" column you will calculate the resistance for each observation.
2. Use connecting wires to connect each end of a D-cell to a terminal on a voltmeter. Record the voltmeter reading in your table. Disconnect the voltmeter.
3. Connect one wire from the D-cell to a terminal of an ammeter. Attach another connecting wire to the other terminal of the ammeter.
4. Clip the free ends of the connecting wires onto the ends of a 10-cm length of pencil lead. Record the reading on the ammeter.
5. Move the clips on the pencil lead so that they are only 1 cm apart. Record any change in the reading on the ammeter.
6. Repeat steps 4 and 5 for the other lengths of substances that you have.

Analyzing and Interpreting

7. Use Ohm's law ($R = V/I$) to calculate the resistance for each current recorded in your table.
8. Which substance had the greatest resistance? Explain any differences in resistance among the substances.
9. What was the effect of moving the connecting wires so that the current travelled through a shorter length of the conductor? Explain.
10. How precise were your measurements? Were there any sources of error that could affect the accuracy of your results?

Forming Conclusions

11. Write a summary that answers the question: Do different materials have different values of electrical resistance? Use your data to support your answer.

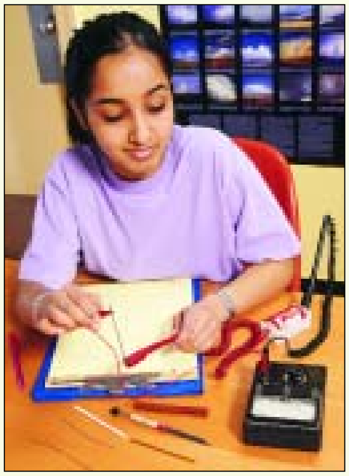


Figure 2.19 Determining resistance

Applying and Connecting

You have probably seen a computer plugged into a surge protector instead of directly into a wall socket. Surge protectors protect sensitive electronic equipment from occasional sudden increases in voltage. These devices rely on special conductors that have variable resistance. If voltage is at normal levels, the current flows normally through the circuit. But if voltage is too high, the resistance of the conductor drops. This allows the potentially dangerous current to be conducted away from the normal circuit to a safety ground wire.

Extending

Alberta homes have to cope with long, cold winters. Sometimes, the water pipes of homes will freeze causing considerable damage. If you had to construct a flexible wrap that you could plug in and wrap around water pipes to keep them warm, what materials would you use? Explain.

Figure 2.20 Resistors come in many shapes and sizes. Remember that the type of material affects the resistance.

Types of Resistors

A wide variety of resistors are made for different applications, especially in electronics. For example, radios and televisions contain dozens of different resistors. Resistors are available with values covering the whole range between conductors (very low resistance) and insulators (very high resistance).

Resistors can be made with a number of techniques and materials, but the two most common types are wire-wound and carbon-composition. A wire-wound resistor has a wire made of heat-resistant alloy wrapped around an insulating core. The longer and thinner the wire, the higher the resistance. Wire-wound resistors are available with values from 0.1 Ω up to 200 kΩ. The wire for a 200 kΩ resistor is very thin.

Carbon-composition resistors are made of carbon mixed with other materials. The carbon mixture is moulded into a cylinder with a wire at each end. By varying the size and composition of the cylinder, manufacturers produce resistances from 10 Ω to 20 MΩ. Moulded carbon resistors are cheaper to make than wire-wound resistors, but less precise.

reSEARCH

Superconductors

Superconductors may bring radical changes in electronics and power transmission. Find out how superconductors might change the world of electrical technology. Prepare a multimedia presentation to summarize your research. Begin your information search at www.pearsoned.ca/scienceinaction.

Check and Reflect

Key Concept Review

1. How is current related to voltage in a circuit?
2. How is current related to resistance in a circuit?
3. What is the difference between a galvanometer and a multimeter?
4. What does the term "voltage drop" mean?

Connect Your Understanding

Use the Ohm's law table on page 306 to answer questions 5 to 9.

5. A bulb of 15-Ω resistance is in a circuit powered by a 3-V battery.
   a) What is the current in this circuit?
   b) What would the current be if you changed to a 45-Ω bulb?
6. A digital recorder plugged into a 120-V outlet has an operating resistance of 10 000 Ω. How much current flows in this device?
7. An electric heater draws 10 A from a 120-V source. What is the heater's resistance?
8. A current of 1.5 A flows through a 30-Ω resistor that is connected across a battery. What is the battery's voltage?
9. A current of 12 A flows through a vacuum cleaner motor that is plugged into a 120-V source. What is the internal resistance of the vacuum motor?

Extend Your Understanding

10. Use the waterfall model to explain flowing electricity. Make sure to include the terms voltage, current, and resistance in your description.

2.3 Analyzing and Building Electrical Circuits

The toy robots in Figure 2.21 have ingenious circuits. The most economical way to connect all the components in a circuit is in a simple loop. But these circuits must be designed so that one component does not depend on the others. For example, it would be frustrating to the user if the whole device stopped working simply because one small light bulb burnt out. With careful attention to circuit design, engineers make sure these devices can perform the tasks that the user wants.

Figure 2.21 These toy robots are controlled by electrical circuits.

QUICKLAB

Flashlight Design

Purpose

To explore circuits by designing a simple flashlight

Procedure

1. Draw a diagram to show how you think the electrical circuits inside an ordinary flashlight are set up.
2. Use cells, connecting wires, switches, and bulbs provided by your teacher to build your own model flashlight based on the diagram you've made.

Question

3 Suppose you had to design an emergency flashlight with a light at each end. How would you add the second bulb to your flashlight without making the first bulb dimmer?

Materials & Equipment

- dry cells
- connecting wires
- switches
- bulbs and holders

Circuit Drawings

Engineers and designers of electrical circuits use special symbols that show the components and connections clearly. These symbols make it easier to plan and analyze a circuit before you build it. A drawing made with these symbols is often called a **schematic** or **schematic diagram**.

Parts of a Circuit

Schematics can sometimes seem complicated, but all circuits have four basic parts: sources, conductors, switching mechanisms, and loads.

- A source provides energy and a supply of electrons for the circuit.
- A conductor provides a path for current.
- A switching mechanism controls current flow, turning it on and off, or directing it into different parts of the circuit.
- A load converts electrical energy into some other form of energy.

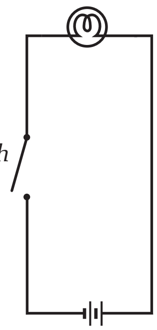
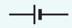
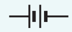


Figure 2.22 The four basic parts of an electrical circuit

infoBIT

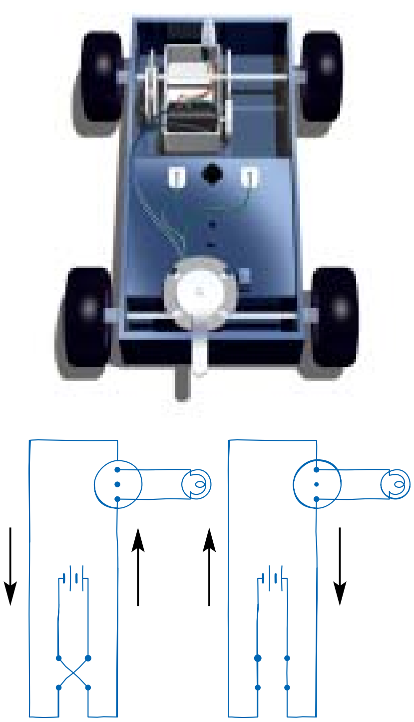
Incredible Shrinking Circuits

Before the 1950s, vacuum tubes were used to control current in electrical circuits. These were so bulky that early computers filled entire rooms. Vacuum tubes have been replaced by tiny components that make today's hand-held computers thousands of times more powerful than the old room-sized ones.

Symbol	Represents	Description
	conductor	conducts electricity through circuit
	cell	stores electricity (large bar is positive)
	battery	combination of cells
	lamp	converts electricity to light
	resistor	controls the amount of current in the circuit
	switch	opens and closes circuit—allows current to flow
	ammeter	measures amount of current in circuit
	voltmeter	measures voltage across a device in a circuit
	rheostat	variable resistor
	motor	converts electricity to mechanical energy
	fuse	melts if current in circuit is too high

Knowing the basic electrical symbols can help you analyze existing circuits. By studying the pathways of wires and components in a device, you can draw a schematic for the circuit. This drawing can make it much easier to understand where the current flows and how the device functions.

(a)



(b) forward **(c)** backward

Figure 2.23 A toy bulldozer and schematics for its circuit. Arrows show direction of current flow.

Circuit Analysis Example—Bulldozer

A student was curious about the toy bulldozer shown in Figure 2.23(a), so she decided to do a circuit analysis of it. She determined that the bulldozer moves forward when its switch is moved to the left and backward when the switch is moved to the right. In its middle position, the switch turns the bulldozer off. A bulb on top of the bulldozer lights up when it moves in either direction. Taking the bulldozer apart, the student determined that it has two loads, a motor and a bulb. She also found two 1.5-V cells that act as the source and a switching mechanism that appears to connect the ends of four wires. She carefully followed the conductors through the whole circuit and produced two schematics showing the circuits for forward and backward movement of the bulldozer. Note that, for clarity, conductors in schematic diagrams are drawn as straight lines, even though the wire may twist and turn in the device.

Parallel and Series Circuits

You may have noticed burned-out bulbs in decorative displays. In order for a bulb to operate, current must travel through it. Sometimes the bulbs are connected in a single string with the current running through each bulb in turn. That means the whole string goes out if any of the bulbs burns out or becomes loose in its socket. Circuits can be designed to avoid this problem.

Series Circuits

The circuit in which the current passes through each bulb in turn is called a **series circuit**. In a series circuit, there is only one pathway for the current, as shown in Figure 2.24. If that pathway is interrupted, the whole circuit cannot function. The other problem with series circuits is that adding components increases the total resistance of the circuit. This decreases the current. Thus, adding an extra bulb to a series string of lights makes all the bulbs dimmer. However, series circuits do have an important use. In household circuits, switches are wired in series with other components (e.g., wall plugs, lights). This makes it possible to turn off all the electricity in the circuit.

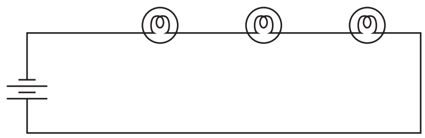


Figure 2.24 Series circuit—there is only one path for current.

Parallel Circuits

Many sets of decorative lights are not connected in series, but in parallel. **Parallel circuits** have a separate current path for each section of the circuit (Figure 2.25). In a parallel-wired string of lights, for example, each bulb has its own path to the current source. An interruption or break in one pathway does not affect the rest of the pathways in the circuit. Similarly, adding a new pathway with more resistors does not affect the resistance in any of the other pathways. In fact, adding extra resistors in parallel decreases the *total* resistance of the circuit. This might seem strange, but remember that adding more paths for the current to take means less total resistance. Think about how much less resistance there is when you drink through two straws instead of one.

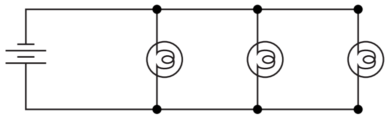


Figure 2.25 Parallel circuit—each component has its own path for current.

QUICK LAB

How Does That Toy Work?

Purpose

To determine the circuit design of an electronic device

Procedure

1. With a partner, carefully take apart the toy vehicle, noting all the parts of the electrical circuit.
2. Draw a schematic diagram for the toy vehicle. Label the loads, conductors, switches, and sources in your schematic. Have other students examine your toy and see if they agree with the schematic you have drawn.

Question

3. Can you design your own, unique toy vehicle? Draw a labelled picture for your toy vehicle and draw a schematic for its circuit.

Materials & Equipment

- an electric toy vehicle or an old or discarded electrical device
- basic tools

Caution!
Make sure your device is **not** plugged in.

Activity D-5

Problem Solving

Wiring a Secure and Safe Home

Recognize a Need

Home outdoor lighting that comes on automatically makes walking safer and deters burglars. How can you design circuitry for a home that includes an automatic exterior light?

Materials & Equipment

- connecting wires
- electricity source (batteries)
- battery holder
- bulbs
- switches
- photoconductor
- flashlight or lamp

Figure 2.26 Photoconductors

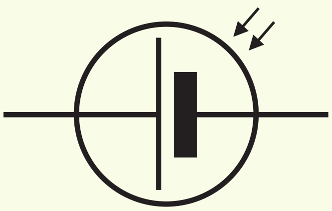


Figure 2.27 Photoconductor symbol

The Problem

You and your partner are charged with the task of designing the basic lighting circuit for the interior and exterior of a small home. The homeowner wants the circuit to include an outdoor light that comes on automatically when someone approaches. **Photoconductors** are devices that allow current to flow when they are exposed to light. Some photoconductors respond to the heat radiated by people or animals. In this lab, you will likely have a visible-light photoconductor and use a flashlight or a lamp to mimic an approaching person.

Criteria for Success

- Draw a schematic for a circuit that provides lighting for three rooms in a home, plus an outdoor light that will come on automatically. Your schematic should also include a method of controlling the electricity in the whole circuit—there must be a way to turn off the electricity to the circuit in order to make repairs or modifications safely.
- Build a circuit that represents the home lighting system you have designed.
  - ❍ The model circuit should have three room lights that can operate independently.
  - ❍ The model circuit's outdoor light should come on automatically (when tested with a flashlight).
  - ❍ The model circuit should have a switch that can successfully turn the electricity off or on for the entire circuit.

Brainstorm Ideas

1 Discuss and sketch designs for your lighting system. Keep in mind the criteria for success and convenience for the homeowner.

2 Consider the materials you have to work with. Remember that you must build what you include in your schematic. You will have access to general electrical supplies such as wires, bulbs, and switches. Do you have all the components you need?

3 Predict which of your designs will best meet the criteria for success.

Build a Prototype

4 Assemble the materials you will need to build your circuit model and construct it.

Test and Evaluate

5 When you have built your circuit, test it to see if it meets the criteria. If you used a visible light-activated photoconductor in your model, you can shine a light onto it to represent a person approaching the home.

Communicate

6 Have classmates examine and test your circuit. Examine the circuits your classmates have built, and suggest an improvement for one of their designs. If someone suggests a design improvement for your circuit, test it.

Applications of Series and Parallel Circuits

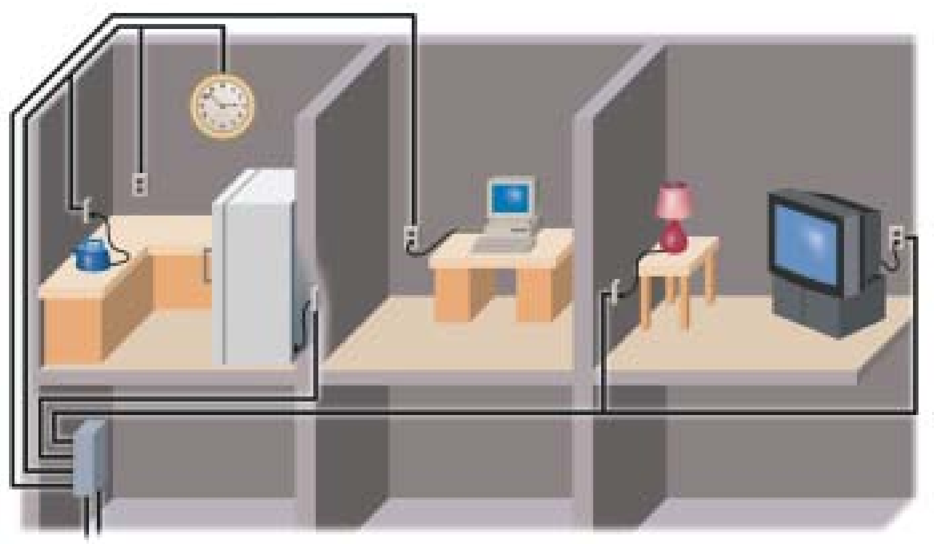


Figure 2.28 A typical home has many parallel circuits.

House Wiring

Household wiring is one of many applications that use parallel circuits. You wouldn't want the power to your refrigerator to go off if a bulb burnt out, would you? This could happen if you wired your lights and wall sockets in series instead of in parallel. However, as you read earlier, you must use a series circuit for switches. A switch in one branch of a parallel circuit controls only the devices in that branch. But a switch in series with all the branches controls all of them. It is an important safety feature to have switches wired in series because it is sometimes necessary to turn off the electricity in part or all of a home.

Microcircuits

Conventional switches are practical and convenient for a home. But for the tiny circuits in advanced electronics applications, **transistors** must be used instead. Transistors are often referred to as solid-state components because they are made of a solid material with no moving parts. Most transistors are constructed with three layers of specially treated silicon. These layers are arranged so that a small voltage through the middle layer controls a current between the outer layers. In this way, transistors can act as switches.

Microcircuits (also called **integrated circuits**) are made up of microscopic transistors and resistors. A microcircuit is exactly what its name suggests: a circuit on an extremely small scale. The latest microcircuits contain more than a million components in a square centimetre!

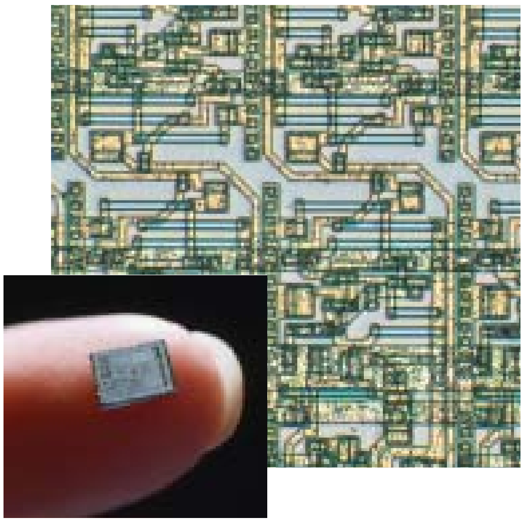


Figure 2.30 A microcircuit is often called a "chip" or "microchip."

reSEARCH

Diodes

Diodes are another type of solid-state component widely used in microchips and other circuits. Find out more about diodes and how they function.

Begin your search at www.pearsoned.ca/scienceinaction.

Summarize your research in a poster.

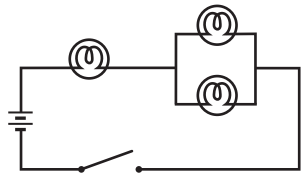


Figure 2.29 A combination circuit. The switch in this circuit can turn all the bulbs on or off.

Check and Reflect

Key Concept Review

1. What are the two types of electrical circuits? Draw a diagram of each type. Use the same components in each diagram.
2. What is a schematic? Illustrate the schematic symbols for a lamp, switch, rheostat, motor, fuse, and ammeter.
3. What is the difference between a cell and a battery in a schematic diagram?
4. How does resistance change as you add bulbs to a series circuit? Explain your answer.
5. What happens to all the bulbs in a parallel circuit when one bulb burns out? Explain your answer.

Connect Your Understanding

6. Is the wiring in a home likely to have series or parallel circuits? Explain your answer.
7. Examine circuits A and B in Figure 2.31.
   a) In which circuit will the bulbs not light up when the switches are closed?
   b) What can be done to correct the problem?
8. What are the differences between the circuits you find in your house and the circuits on a microchip in a computer?
9. Why are motors, lamps, and other resistors considered “loads” in electrical circuits?

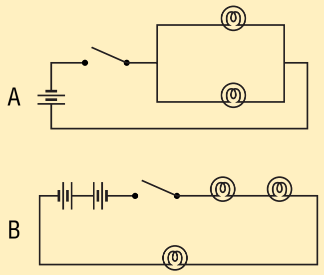
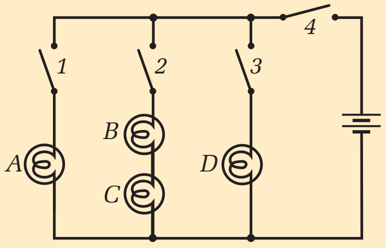


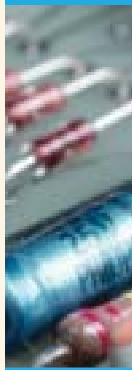
Figure 2.31 Circuits for question 7

Extend Your Understanding

10. You have been asked to design a toy that looks like a dancing chicken. The toy must have an on/off switch and a motor that operates whenever a light shines on the toy. Draw a schematic for the toy.
11. The circuit in Figure 2.32 has four bulbs (A–D) and four switches (1–4). Use Figure 2.32 to answer the following questions:
    a) Which switch(es) should be closed to light bulbs A and D only? Explain.
    b) Which switch(es) should be closed to light bulb A only? Explain.
    c) Which switch(es) should be closed to light bulbs B and C only? Explain.
    d) How would you operate this circuit so that you could turn all the lights on and off with a single switch?
    e) Is it possible to operate bulbs B and C independently of each other? Explain. If not, suggest a change to the circuit that would make this possible.

Figure 2.32 Circuit for question 11





Assess Your Learning

Key Concept Review

1. Three quantities can be used to describe the flow of electricity in a circuit. Name each quantity, the unit of measurement, and the device used to measure it.
2. A student measures the current in a circuit as 0.50 A. The circuit has two resistors connected in series: one is 110 Ω and the other is 130 Ω. What is the voltage in the circuit?
3. A firetruck has a searchlight with a resistance of 60 Ω which is placed across a 24-V battery. What is the current in this circuit?
4. A table lamp draws a current of 200 mA when it is connected to a 120-V source. What is the resistance of the table lamp?

Connect Your Understanding

5. You are given an unmarked resistor of unknown value. You have a selection of electronics equipment, including connecting wires, cells, and meters. Describe how you would determine the approximate value of the resistor.
6. Draw a circuit schematic that contains two motors and a lamp, all connected in parallel. Include two switches in this schematic: one to operate the lamp and one to control the whole circuit.

Extend Your Understanding

7. Explain how the person drinking a milkshake through a straw in Figure 2.33 could be used as a model for electrical current in a resistor.
8. You find an old string of decorative lights in your grandparents' attic. The wiring appears safe, so you buy new bulbs for the string and screw them in. But none of them work when you plug in the string. Explain the likely cause of this problem.
9. Draw a circuit schematic for a battery-operated, variable-speed electric fan. What makes it possible to vary the speed of the fan?

Figure 2.33 Question 7: Drinking a milkshake through a straw

Focus On SCIENCE AND TECHNOLOGY

The products of technology are devices, systems, and processes that meet given needs and wants. For example, conductors, insulators, and resistors in your home control electricity used in lights, appliances, and other devices.

1. Describe two devices or systems you read about in this section.
2. What needs or wants were these devices designed to meet?
3. Name other devices or systems that meet these same needs. Why do you think different devices and systems are developed to meet the same needs?

3.0 Devices and systems convert energy with varying efficiencies.

Key Concepts

In this section, you will learn about the following key concepts:

- forms of energy
- energy transformation
- generation of electrical energy
- energy transmission
- measures and units of electrical energy

Learning Outcomes

When you have completed this section, you will be able to:

- identify, describe, and interpret examples of mechanical, chemical, thermal, and electrical energy
- describe evidence of energy transfer and transformation
- identify forms of energy inputs and outputs
- apply appropriate units, measures, and devices in determining and describing quantities of electrical energy
- construct, use, and evaluate devices for transforming mechanical energy to electrical energy and electrical energy to mechanical energy
- evaluate modifications to electrical devices
- apply the concepts of conservation of energy and efficiency to the analysis of energy devices
- compare energy inputs and outputs of a device, and calculate its efficiency
- describe techniques for reducing energy waste in common household devices

Energy is all around us in many different forms—light from lamps, sound from stereos, heat from furnaces and stoves. Yet we rarely think about how much energy we use in a day. It has been estimated that it would take 2800 hours of strenuous manual labour to produce as much energy as a typical Canadian uses daily. You would need a team of 350 people working for eight hours straight to supply the energy for just one person.

In this section, you will learn about four common forms of energy—chemical, electrical, mechanical, and thermal—and how they can be transformed into other forms. This will help you understand and measure energy inputs and outputs, and calculate the efficiency of devices and systems. You will also use this knowledge when you consider ways to reduce energy wasted by household devices.

For Web links relating to 3.0, visit **www.pearsoned.ca/scienceinaction**

3.1 Energy Forms and Transformations

Figure 3.1 Energy transformations make this work possible.

When we are exhausted we might say that we don't have the energy to do any more work—we know that work requires energy. In fact, the scientific definition of **energy** is the ability to do work.

In Figure 3.1, several kinds of energy are being used to do work. The lawnmower's motor is using electrical energy to spin the cutting blade, but the lawnmower will not move forward unless it is pushed. Chemical reactions in the muscles of the person pushing the lawnmower provide the energy to move it across the lawn. The chemical energy from her muscles is converted into the motion or mechanical energy of the lawnmower. Chemical energy is also converted to thermal energy as her muscles strain to push the lawnmower.

The photo shows examples of four common forms of energy and the transformations that occur between them. The following chart can help you understand these different forms of energy.

Four Common Forms of Energy

Energy Form	Description
Chemical Energy	The energy stored in chemicals. This is a form of potential or stored energy. This energy is released when chemicals react.
Electrical Energy	The energy of charged particles. Electrons are negatively charged. Electrical energy is transferred when electrons travel from place to place.
Mechanical Energy	The energy possessed by an object because of its motion or its potential to move. A thrown baseball has mechanical energy because of its movement and its potential to fall.
Thermal Energy	The total kinetic energy of all the particles in a substance. The faster a particle moves, the more kinetic energy it has. Compare two cups holding equal amounts of water: the one containing more thermal energy will feel warmer.

infoBIT

The Joule

Englishman James Joule (1818–1889) contributed greatly to our understanding of energy by proving that both mechanical work and electricity can produce heat and vice versa. In recognition of the importance of his research, scientists named the unit of energy the joule (symbol J).

GIVE IT A **TRY**

GOING SHOPPING

Examine the photo of the shopper in Figure 3.2, and answer the following questions:

- The shopper is using his muscles to push the grocery cart. What energy transformation is involved?
- Thermal energy is constantly produced by chemical reactions in our bodies. What transformation or transfer takes place when we are in an environment that is cooler than our bodies?
- The wheelchair is powered by a battery. What energy transformation takes place in the wheelchair?
- What form of energy does the wheelchair have when it is rolling?
- Suppose the battery fails and the wheelchair must be pushed by hand. What energy transformation would take place?

Figure 3.2 Every activity involves energy transformations.

CHEMICAL ENERGY

You have probably felt weak and tired when you have gone for long periods without a meal. This results from a lack of energy-producing molecules in your bloodstream and cells. **Chemical energy** is the energy that is found in chemicals, including food. A common molecule used for the production of energy in humans is glucose, a type of sugar (Figure 3.3). Your cells use glucose molecules and a series of chemical reactions to produce thermal energy to keep you warm and mechanical energy so that you can move.

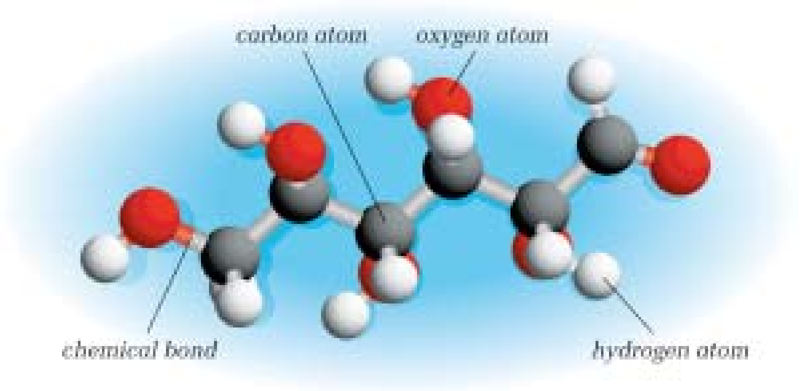


Figure 3.3 Glucose molecules are used in the production of energy for your body.

Chemical energy can be transformed to other forms of energy as well. For example, when you use a battery-operated CD player, you are transforming chemical energy into other forms. Recall from earlier lessons that a dry cell contains chemicals that react to produce electrical energy. The CD player transforms this electrical energy into mechanical and sound energy.

Another example of a transformation involving chemical energy is the use of explosives to demolish large buildings. These buildings must be brought down quickly to save money and time, but they must also be brought down safely. Carefully placed and well-timed dynamite explosions are often the best choice for the task. The chemical energy in the dynamite is rapidly released to provide the mechanical energy that demolishes the building.

Figure 3.4 Part of the mechanical energy in a building demolition is transformed from the chemical energy of explosives. Much of the energy in the demolition comes from the gravitational potential energy of the building itself. The collapse of the support columns triggers the release of this energy.

Transformations Involving Chemical and Electrical Energy

You can use various devices to transform electricity into other forms of energy. Depending on the electrical device, electricity can be transformed into any form of energy you require, such as heat, light, sound, or movement (mechanical energy).

Examples of Devices That Convert Energy from One Form to Another

Input Energy	Device	Output Energy
electrical	toaster	thermal
chemical	flashlight	electrical, then light and thermal
electrical	blender	mechanical
chemical	battery-operated clock	electrical, mechanical, sound

ACTIVITY D-6

Problem Solving

TRANSFORMING HEAT INTO ELECTRICITY

Recognize a Need

There are locations where it is impossible or inconvenient to measure temperature with an ordinary thermometer; for example, inside a car engine or a baker's oven. One way to keep track of temperatures in such locations is to convert some of the heat into electricity and then use that electricity to gauge the temperature.

The Problem

You have been asked to design a method of monitoring the temperature inside a kiln in a pottery studio. The potter has built a kiln but needs a way of measuring the temperature inside to ensure that the pottery is fired properly. You will be testing a **thermocouple**, a simple device that can convert heat to electricity.

Criteria for Success

- You must produce a sketch to show how you could use a thermocouple to measure the temperature inside a very hot, closed environment, such as a kiln.
- You must prove that your thermocouple device is capable of converting heat into electricity and that it will work at high temperatures.

Brainstorm Ideas

1 Discuss how to convert electricity produced by a thermocouple into a display of temperature. Keep in mind that the system should be convenient to use and read.

Test and Evaluate

Steps 2 to 7 can be done as a teacher demonstration.

2 Use wires to connect the ends of the thermocouple to the voltmeter.

3 Light the Bunsen burner and rotate the barrel to obtain a blue flame.

4 Hold the end of the thermocouple in the beaker of ice water. Observe and record the reading on the voltmeter.

5 Using tongs, hold the very tip of the thermocouple still in the bottom of the flame. Observe and record the reading on the voltmeter.

6 Return the thermocouple to the ice water, again recording any reading on the voltmeter.

7 Repeat steps 4 to 6 at least three times. Each time hold the thermocouple in a different part of the flame, such as middle, side, or top.

Communicate

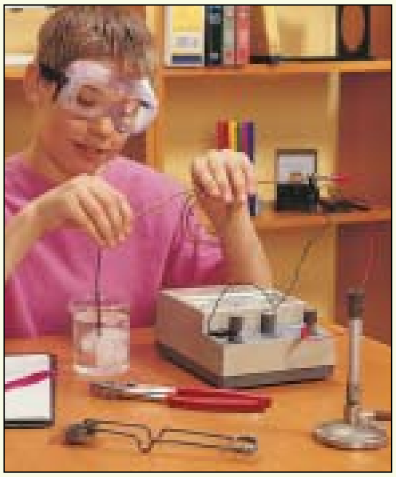
8 What is the relationship between the voltage produced by the thermocouple, its position in the flame, and temperature?

9 Why do you think the device used to produce electricity in this activity is called a "thermocouple"?

10 Do your results indicate that the thermocouple will be appropriate for your design for measuring the temperature in a kiln? Explain.

Materials & Equipment

- thermocouple
- beaker
- Bunsen burner
- heat resistant tongs or pliers
- ice water
- connecting wires
- millivoltmeter



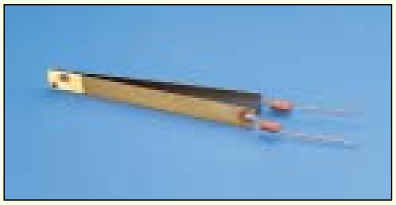


Figure 3.5 Two types of thermocouples

Caution!
Be very careful when working with open flames.

Transformations Between Thermal and Electrical Energy

A **thermocouple** is a device that can convert thermal energy to electrical energy. It consists of two different metals joined together that conduct heat at slightly different rates. When the metals are heated, this difference in conduction results in electricity flowing from one metal to the other. The temperature affects the amount of electricity produced, so you can use a thermocouple as a thermometer.

Thermocouples are very useful for measuring temperatures in areas that are difficult to access or that are too hot for a liquid-filled glass thermometer. For example, some Alberta farmers hang thermocouple cables in their grain bins. The amount of electricity the cable produces indicates whether the grain is getting too hot. This can happen if the grain is too moist.

Devices such as heaters and ovens do the exact opposite of a thermocouple. They convert electrical energy into thermal energy. Think of the heating element in the oven. The energy of the electrical charges is transferred to the atoms of the metal that the charges flow through. The metal heats up and warms the oven. Changes in thermal energy can be measured by keeping track of the temperature of the substance.

reSEARCH

Ocean Thermal Energy Conversion (OTEC)

Scientists are researching ways to use the ocean's natural thermal differences to generate electricity. The temperature difference between the warm surface and cold depths can be 20°C or more. This difference can be used to make electricity through ocean thermal energy conversion (OTEC). Find out how OTEC works. Use labelled diagrams and flowcharts to summarize your research. Begin your information search at www.pearsoned.ca/scienceinaction.

Check and Reflect

Key Concept Review

1. What is energy?
2. What energy transformations take place in each of the following devices?
   - electric kettle
   - battery-operated toy car
   - electric blanket
   - cordless telephone
3. What does a thermocouple do?
4. What is thermal energy?
5. What is the difference between mechanical and chemical energy?

Connect Your Understanding

6. a) What form of energy is found in sugar?
   b) How is that energy used in your body?
7. A model rocket uses a flammable fuel to power its flight into the air. What energy transformation takes place in the rocket?
8. In what way is an electric oven the opposite of a thermocouple?

Extend Your Understanding

9. Why is a thermocouple a good device for indicating the temperature in a car engine?

Figure 3.6 Hans Christian Oersted

*info***BIT**

Vacuum Cleaner

Vacuum cleaners work with the help of an electric motor. The motor has a fan attached. When it spins, the blades of the fan force air out, which creates suction inside the vacuum cleaner. Air from the room forces its way into the vacuum, carrying dirt with it.

3.2 Energy Transformations Involving Electrical and Mechanical Energy

Motors have a place in many of the electrical devices that we use every day. The beginnings of this important energy converter—the motor—can be traced back to the early 1800s. In 1820, Danish scientist Hans Christian Oersted conducted a famous demonstration in which he deflected a compass needle with a current-carrying wire. A compass needle is magnetic. If a nearby electrical current affects it, there must be some relationship between electricity and magnetism. Oersted had discovered that current flowing through a wire creates a magnetic field around the wire.

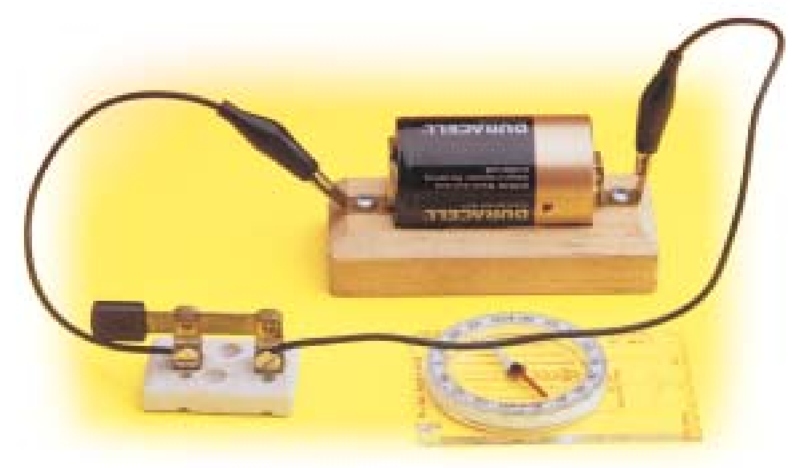


Figure 3.7 Electricity flowing through the wire causes the compass needle to deflect.

Eleven years later, Michael Faraday constructed a device that used electromagnetic forces to move an object. The design was crude and produced little power, but it proved that electricity could produce continuous motion. In Faraday's device, a hanging wire circled around a fixed magnet. A pool of mercury maintained the connection to the moving wire. We now know that mercury is highly toxic, so an open container of mercury would never be used today. Faraday also made a device in which a magnet rotated around a fixed wire. Faraday's devices led to the development of the electric motors that we use.

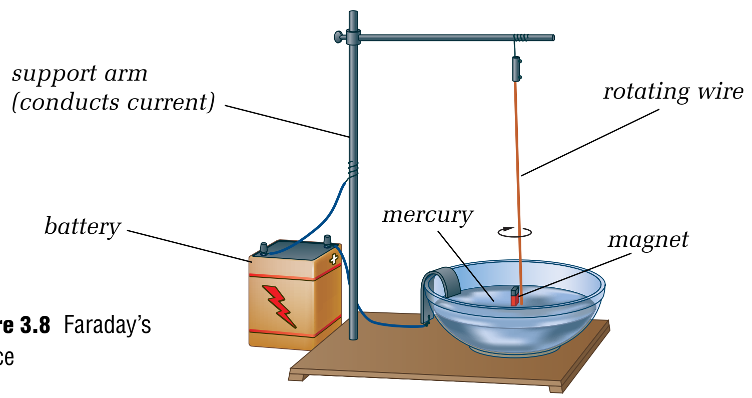


Figure 3.8 Faraday's device

Electric Motors

Early experimenters found that they could make a strong **electromagnet** by winding current-carrying wire into a coil (usually around an iron core). They also found that an electromagnet will move to line up with the magnetic field from a nearby permanent magnet. This is the same way that two permanent magnets attract each other.

How do you keep an electromagnet spinning in a magnetic field? The trick is to switch the direction that the current travels through the coil just as it aligns with the magnetic field of the permanent magnet. Reversing the current reverses the polarity (the north and sounds ends) of the electromagnet. It will then continue turning in order to align the opposite way. Changing the polarity of the electromagnet every half turn causes the electromagnet to be continuously pushed and pulled by the permanent magnet.

Many electric motors use a **commutator** and **brushes** to reverse the flow of electricity through the electromagnetic coil. The commutator is a split ring that breaks the flow of electricity for a moment and then reverses the connection of the coil (see Figure 3.10(a)). When the contact is broken, so is the magnetic force. But the **armature** continues to spin because of its momentum. (The armature is the rotating shaft with the coil wrapped around it.) As a result of the spinning, the commutator reconnects with the brushes. The magnetic force on the coil keeps it spinning continuously (Figure 3.10(b)). The brushes are usually bars of carbon pushed against the metal commutator by springs. They make electrical contact with the moving commutator by "brushing" against it.

Figure 3.9 An electromagnet is made by winding a current-carrying wire around a metal core.

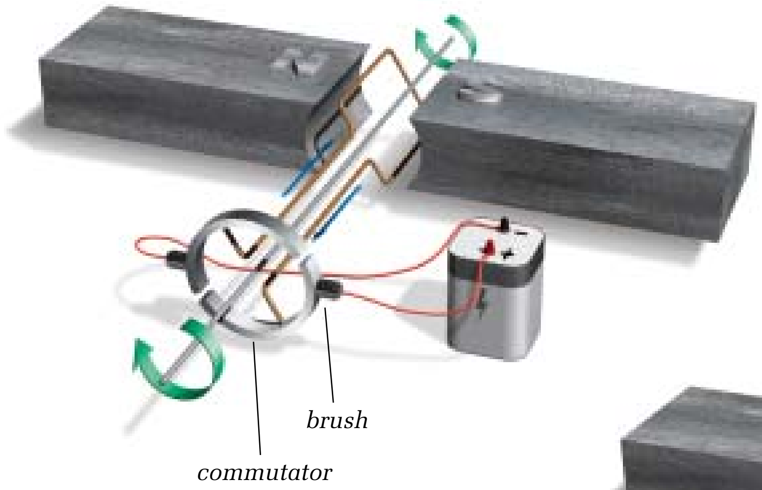


Figure 3.10(a) Current flowing through the wire coil creates a magnetic field around the wire. This interacts with the permanent magnets, making the coil spin.

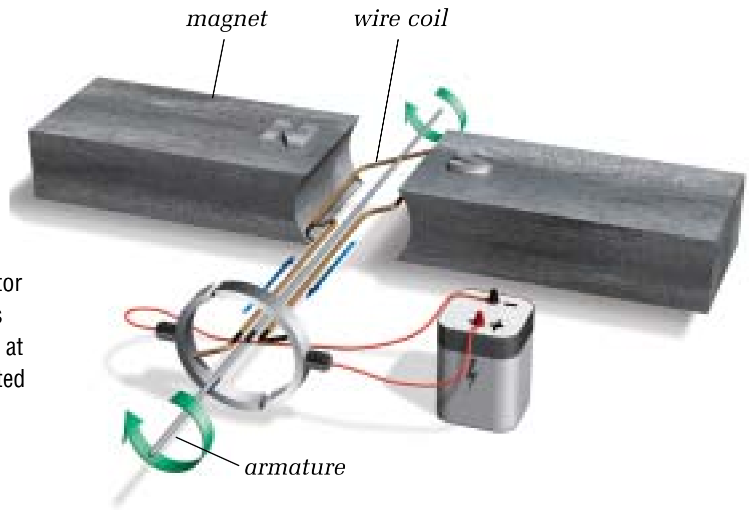


Figure 3.10(b) As the coil spins, the commutator changes position so that its other half contacts the other brush. This reverses the current flow at just the right time. The magnetic force is directed on the coil to keep it spinning.

ACTIVITY D-7

Problem Solving

GET YOUR MOTOR RUNNING

Recognize a Need

A toy manufacturer has developed a motor-building kit. Before they can market it, they need to know if their kit is suitable for both beginners and more advanced hobbyists.

Materials & Equipment

- 1.5-V D-cell
- 1 m of thin enamel-coated wire (22-28 gauge)
- paper clips
- tape
- sandpaper
- empty film canister
- circular magnet

Figure 3.11 Building a simple motor

The Problem

The toy manufacturer would like you to test the kit. They would also like you to write instructions for users on how to alter the motor so that it will spin at different speeds and in the opposite direction. The manufacturer has encouraged you to design your own motor, if you wish, and write building instructions for it.

Criteria for Success

- Build a functioning electric motor with simple materials. Do your best to complete as many of the following tasks as you can. Each level is more difficult as you go from level 1 to level 5.
  - ❍ Level 1: your motor shows movement
  - ❍ Level 2: your motor can turn a half-turn to a full-turn
  - ❍ Level 3: your motor can spin continuously
  - ❍ Level 4: your motor can be adjusted to spin at different speeds
  - ❍ Level 5: your motor can spin in different directions

Brainstorm Ideas

TOOLBOX

1. Before you begin, read Toolbox 3 about the problem solving process.
2. Make a sketch of what your motor will look like when it is completed. Show it to your teacher for approval.
3. Consider the materials you have to work with. You have to build a working model that must be easy to adjust.

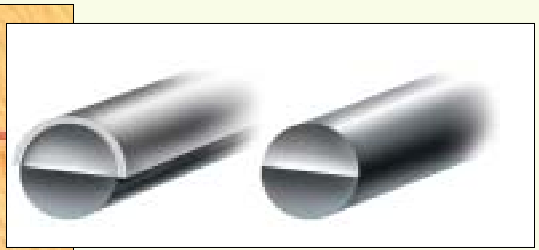
Build a Prototype

4 Assemble the materials you need and construct your motor. If you wish, you may instead build the toy manufacturer's motor design by following steps 5 through 8.

5 Use the film canister to wrap the length of wire into a coil. Leave 5 to 6 cm of wire free at each end of the coil. To keep your wire coil from unwinding, wrap the free ends around the coil a few times, as shown in Figure 3.12(a).

6 Use sandpaper to remove the enamel coating from one end of the wire. Then hold the coil on edge and sand off the enamel coating from only the bottom half of the other end of the wire. Figure 3.12(b) shows the wire's ends. When you are done, your wire coil should look like the one in Figure 3.10(a). This is your motor's armature.

Figure 3.12(a) The motor's armature



(b) The finished ends of the wire

7 Bend two paper clips so that they can support the wire coil and be attached to the ends of the D-cell. Use tape to hold the bent paper clips in contact with the metal ends of the cell, as shown in Figure 3.11. Attach the circular magnet to the D-cell as shown in Figure 3.11.

8 Place the coil so that it rests on the clips. Give the coil a small push to see if it will spin. Adjust these components to minimize friction and get the loop spinning as smoothly as possible.

Test and Evaluate

9 When your motor is complete, test it to see if it meets some or all of the criteria for success listed on the previous page. Make adjustments as necessary. Record what you have done and the adjustments you have made.

Communicate

10 Explain why the coil of wire in your motor spins.

11 Did your coil spin better in one direction than another? Explain why it did or did not.

12 Suggest two ways that you could change the design of your motor to make it function better. Make these changes and test your motor again.

13 Have your classmates examine and test your motor. Examine the motors of your classmates and suggest modifications that could improve their designs. If someone suggests a design improvement for your motor, test the suggestion.

14 Write clear instructions on how to build a motor like yours. Include advice on how to make adjustments like the ones you made. Use diagrams wherever they would be helpful. To see if your instructions are easy to follow, have another student or group read them. Revise your instructions as necessary to make them clearer.

Figure 3.13 Turning a steering wheel is similar to the turning of the armature in a motor.

The Steering Analogy

The commutator's role in helping the armature to spin continuously can be hard to understand. Imagine trying to turn a steering wheel. You put both hands on the wheel and turn. Can you keep turning without letting go? You can't because your hands must release and return to their starting position in order to keep turning the wheel.

If you could not let go, you could only turn the wheel one-half turn, then you'd be stuck. The same problem occurs with the motor. Without the split-ring commutator, the armature would turn only one-half turn, then it would stop, locked into place by magnetic attraction.

*QUICK*LAB

St. Louis Motor

A St. Louis motor is designed to show how an electric motor works.

Materials & Equipment

- St. Louis motor

Purpose

To identify the parts of a St. Louis motor and examine its operation

Procedure

1. Draw a diagram of the motor, identifying all the parts: wire coil, brushes, commutator, magnets, and armature.
2. Use connecting wires and a battery to supply electricity to your motor. Start the motor by giving it a spin. Turn off the lights in the room and observe the commutator closely.
3. Alter the position of the magnets in the motor to move them closer, then farther away from the armature. Carefully observe the armature.

Questions

4. Explain what you observed in step 2.
5. Explain what you observed in step 3.

Direct and Alternating Current

Some motors run on **direct current** (DC). It's called "direct" current because the electricity flows in only one direction. Many devices such as mp3 players, computers, cell phones, and calculators also use DC. The electricity in your household circuits is **alternating current** (AC). It's called "alternating" because it flows back and forth 60 times per second. Plug-in devices that require DC come with their own power supplies. The power supply converts the power company's 120-V AC to DC and supplies the voltage that the device requires.

Transformers

Power companies generate AC because, with AC, they can use **transformers** to change the amount of voltage with hardly any energy loss. Voltage change is necessary because the most efficient way to transmit current over long distances is at high voltage. Some transmission lines carry current at 500 000 V. These high voltages must be reduced before the current can be used in your home.

Figure 3.14 shows how this is done. The current-carrying wire is wrapped around one side of an iron ring called a core. This is the primary coil. A secondary coil is wrapped around the other side of the core. The AC current flowing through the primary coil creates an alternating magnetic field. This induces a current in the secondary coil. If the number of loops in the two coils is different, the voltage is transformed down (Figure 3.14(a)) or up (Figure 3.14(b)).

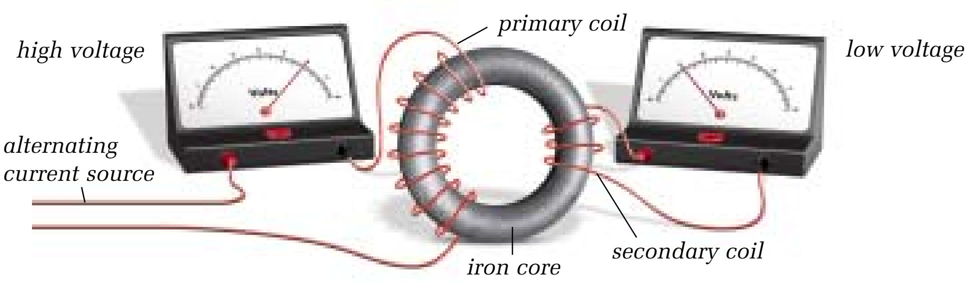


Figure 3.14(a) A step-down transformer reduces voltage.

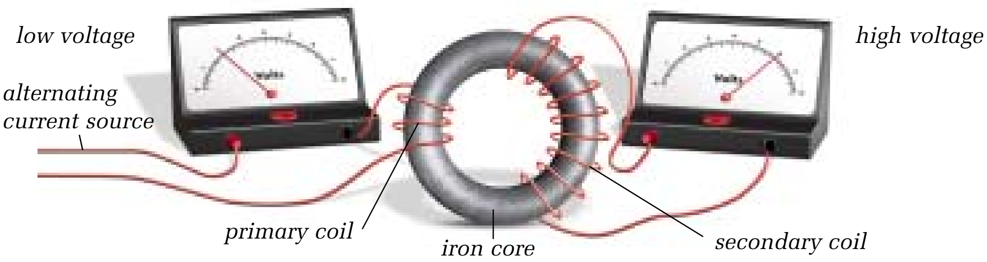


Figure 3.14(b) A step-up transformer increases voltage.

Generating Electricity

In 1831, Michael Faraday made one of the most significant electrical discoveries: **electromagnetic induction**. He demonstrated that electrical current could be generated by moving a conducting wire through a magnetic field. Faraday moved a magnet back and forth inside a coil of wire that was connected to a meter that could detect small electric currents. His discovery changed the world by introducing a way to generate a steady supply of large amounts of electricity.

The hand-held generator in Figure 3.15 moves a coil of wire past permanent magnets. As long as you keep turning, electricity will be produced. The faster you turn, the more current is generated. The same principle of electromagnetic induction is used in large-scale power plants. Massive coils of wire rotating in huge generators produce enough electricity to power whole cities. Such generators provide the electricity we use every day.

reSEARCH

A Wind-up Radio

This radio runs on muscle power. The crank winds a spring. As the spring unwinds, it turns a small generator that produces electricity to run the radio. Find out why engineers thought it would be impossible to build a wind-up radio. Prepare a report about the radio and include a diagram to show how it works. Explain how this invention is helping people in developing countries. Begin your information search at www.pearsoned.ca/scienceinaction.

Spring-powered radio

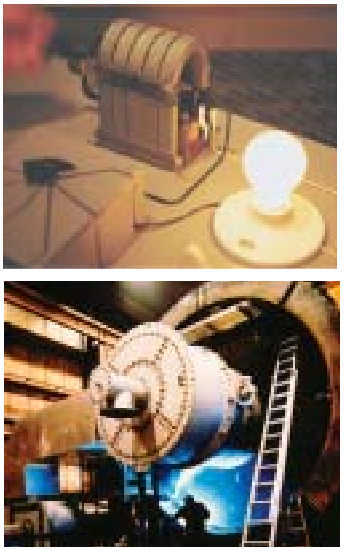


Figure 3.15 Both generators have coils that rotate in a magnetic field.

Activity D-8

Experiment **on your own**

Generating Electricity

Before You Start

You know that electricity can be transformed into mechanical energy by a motor. The reverse is also true. Transforming mechanical energy into electrical energy can be done with a generator. The generator consists of a rotating coil, magnets, and a device to create the turning motion. For example, the turning motion from a wind turbine or water wheel can turn the coil. The turning of the coil through a magnetic field creates, or induces, a voltage. This voltage can be measured with a voltmeter. In this experiment, you will build and modify a generator to induce the highest possible voltage.

The Question

How can mechanical energy be converted to electrical energy?

Design and Conduct Your Experiment

TOOLBOX

1. In your group, brainstorm the materials and equipment you will need to build your generator.
2. List any safety concerns that you need to consider.
3. Develop a plan to build your generator. Show your plan to your teacher for approval.
4. Build your generator.
5. Test your generator to see if it can produce a voltage. You may want to read Toolbox 3 on problem solving to help you improve your design. Remember you will probably need to make several modifications to your design before it works.
6. Once your generator is working, create a hypothesis about the effect of modifying your generator to create a higher voltage.
7. Modify your generator.
8. Compare your results with your hypothesis. Was your hypothesis correct? If not, how would you explain your experimental results?

Figure 3.16 Building a generator

9. Compare your results with those of your classmates. Were your results similar? If there were differences, explain them.
10. Compare your experimental procedure with your classmates' procedures. Identify some strengths and weaknesses of the different ways of collecting and displaying data.
11. Are there any questions or problems that came up during your experiment that would take more investigation to answer? Outline how you would design an experiment to look into these questions or problems.

Generating DC and AC

A DC generator is structurally the same as a DC motor like the one in Figure 3.10—the spinning armature produces electricity. If you run electricity through a DC generator, it will spin like a motor.

An AC generator is slightly different. The central axle of an AC generator has a loop of wire that is attached to two slip rings. Recall that when a wire moves in a magnetic field, current is generated in the wire. Examine Figure 3.17 carefully. You can see that as the axle and loop of wire turn, one side of the loop moves up, and the other side moves down through the magnetic field. When the wire moves up between the magnets, current flows one way in the wire. But when the wire moves down, the current moves in the other direction. This is how the current switches back and forth in the wire with each complete turn of the loop.

The slip rings attached to the wire loop ends conduct the alternating current to the circuit through brushes. The brush and slip ring arrangement allows the whole loop to spin freely. In large AC generators, such as those in a power station, many loops of wire are wrapped around an iron axle-core.

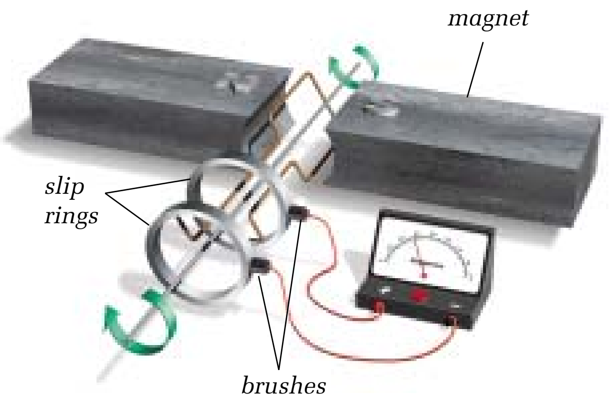


Figure 3.17 The central axle of an AC generator has a loop of wire that is attached to two slip rings.

Check and Reflect

Key Concept Review

1. What is meant by the term "polarity"?
2. Use words and a drawing to describe how to construct a simple electromagnet.
3. Explain the function of the permanent magnets in an electric motor.
4. Describe Faraday's contributions to the development of the motor and the generator.

Connect Your Understanding

5. *A generator stores electric current.* Explain why you agree or disagree with this statement.
6. How are electricity and magnetism related?
7. The permanent magnets of a motor are replaced with more powerful ones. What effect do you think this would have on motor rotation? Explain.
8. Suppose a classmate constructed an electric motor with a solid commutator. That is, the commutator has no split. This solid commutator is in constant contact with the motor brushes. Would this motor design work? Explain why or why not.

Extend Your Understanding

9. You are lost with a group of friends in the deep woods. You notice that the group leader is determining direction with a compass that is taped to the top of his flashlight. Explain why this is a concern.
10. *A motor and a generator are the same thing.* Explain why you agree or disagree with this statement.

Figure 3.18 Cars powered by batteries (top) and hydrogen (bottom)

3.3 Measuring Energy Input and Output

We use energy in every aspect of our daily lives—driving to work or school, heating our homes, preparing our food, watching television. Sometimes, we can choose which kind of energy we will use. For example, we could use electricity, gasoline, natural gas, propane, or hydrogen to power a vehicle. But how do we know which is best? To determine that, we need to measure the types and amounts of energy going into and coming out of the devices we use.

Power

Power is the rate at which a device converts energy. The unit of power is the **watt** (W), named for the Scottish inventor and engineer, James Watt. A watt is equal to one joule per second. The faster a device converts energy, the greater its power rating.

For an electrical device, the power is the current multiplied by the voltage. Mathematically, the relationship between power (P), current (I), and voltage (V) is $P = I \times V$ (watts = amperes × volts). Think of our model using waterfalls. The power of a waterfall is equal to the amount of water flowing times the difference in potential energy between the top of the falls and the bottom. This is just like current flow times potential drop in a circuit.

info**BIT**

Garbage In… Energy Out!

Some cities burn garbage to generate electricity. Tokyo has a waste-to-energy plant that burns 1800 t (tonnes) of garbage a day to produce 50 MW (megawatts) of electrical power.

Example

A hair dryer has a power rating of 1000 W. It is plugged into a 120-V outlet. What is the current flowing through the hair dryer?

Steps to Solving the Problem	Information and Solution
1. Identify known quantities.	power (P) = 1000 W, voltage (V) = 120 V
2. Identify the unknown quantity.	current (I)
3. Use the correct formula.	$I = P/V$
4. Solve the problem.	$I = P/V$ = 1000 W/120 V
	$\boldsymbol{I}$ **= 8.33 A**

Most small appliances in your home have a power rating of 1500 W or less. An electric stove might have a power rating of 7000 W, while the rating for a calculator could be only 0.4 mW.

Figure 3.19 You may be able to determine a product's power rating from its label.

Energy

You can use the power rating of a device to determine the amount of energy the device uses. Recall that power is the rate at which a device converts energy. You can find the amount of energy converted by multiplying this rate by the length of time the device operates. The energy consumption of an electrical device is its input power multiplied by the time the device is used: $E = P \times t$. Recall that energy is measured in joules (watts × seconds).

Example

A microwave oven has a power rating of 800 W. If you cook a roast in this oven for 30 min at high, how many joules of electrical energy are converted into heat by the microwave?

Steps to Solving the Problem	Information and Solution
1. Identify known quantities.	power (P) = 800 W , time (t) = 30 min
2. Identify the unknown quantity.	energy (E)
3. Use the correct formula.	$E = P \times t$
4. Solve the problem.	$E = P \times t$ = 800 W × 30 min E = 800 J/s × 30 min × 60 s/min **E = 1 440 000 J = 1.4 MJ**

Kilowatt Hours

It doesn't take common electrical devices long to consume a large number of joules. For this reason, the **kilowatt hour** is often used as a unit for energy. The energy calculation is the same, except that hours are substituted for seconds, and kilowatts (kW) are substituted for watts. For the microwave oven in our example, the calculation would be E = 0.8 kW × 0.5 h = 0.4 kW·h.

Electricity meters measure the energy used in kilowatt hours. The electric company then bills you for every kilowatt hour used. This cost can add up—a Canadian family's energy bill can be over $100 a month.

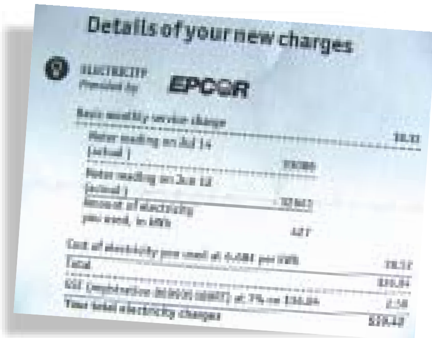


Figure 3.20 An energy bill for a household shows the amount of electricity used in kilowatt hours.

Skill Practice

Power Practice

Use a list from your teacher or use electrical devices at home to look at power ratings. Be careful! Unplug an electrical device before you handle it. Look at items such as light bulbs, curling irons, coffee makers, and clock radios. Record as many ratings as you can in a chart.

On some items, you may find voltage and current listed instead of power. In these cases, calculate the power rating of the device.

Estimate the amount of time that each device is used in a month in your home or in a typical home, then calculate the amount of energy it consumes.

Activity D-9

Problem Solving

Circuit Assessment

Recognize a Need

You have been approached by a couple who have just purchased a small, old recreational vehicle (RV). The RV has a few electrical components they would like to test. The couple want a tutorial on how to measure voltage, current, and power in a circuit. When you ask the couple whether the RV is wired in series or in parallel, they aren't sure.

The Problem

Build model series and parallel circuits to show how to assess the following:
- voltage across each item in a circuit
- current in each branch of a circuit
- power usage by each component

Criteria for Success

TOOLBOX

- You must build an operating example of a series and a parallel circuit. Each circuit should have three components in addition to a voltage source. You can reuse components from one circuit when building the next.
- You must test all components in each circuit for voltage drops. You must also measure the current in each circuit. Keep in mind that you must check each branch in the parallel circuit. (Review section 1.2 for proper use of voltmeters and section 2.2 for proper use of ammeters.) You must calculate the power used by all load components in each circuit.
- You must report your results in tables and graphs that clearly illustrate the difference between the two circuits you have analyzed. (See Toolbox 7 for information on graphing.)

Brainstorm Ideas

1 You will be working in teams. As a team, brainstorm possible approaches to solving the problem and providing the required analysis. Once you have decided on the best procedure, proceed to the next step.

Build a Prototype

2 Draw a schematic for the series and the parallel circuits you will build. Note on your drawings where you will be connecting your voltmeter and ammeter. Make a rough plan of the table(s) and graph(s) you will use to report your results and calculations. Show your design to your teacher for approval.

3 Assemble your materials and build your circuits.

Test and Evaluate

4 Test your circuits to ensure they are working. Then use meters to take the measurements you have designated in your sketches. Record all voltage readings, current readings, and power calculations, and present them in a table. Draw the graph(s) to compare your results for the two circuits.

Communicate

5 How did the power used by the components in the two circuits compare? Can you explain any differences?

6 Look at the circuits and results produced by classmates. Are their results similar to yours? If they are different, can you explain why?

7 Suggest one improvement to your procedure.

Materials & Equipment
- cells or batteries
- cell holders
- motors
- bulbs and holders
- switches
- connecting wires
- voltmeters and ammeters, or multimeters

Figure 3.21 Materials you could use to demonstrate circuit analysis

Figure 3.22 Even a water system dissipates energy because of friction.

Energy Dissipation

Scientists have found that energy cannot be created or destroyed. Energy does not just appear or disappear—it can only be transformed from one form to another. This fundamental principle is known as the **law of conservation of energy**. However, we usually find that the output energy of a device or system is smaller than the input energy, sometimes much smaller.

Most often, the missing energy is lost or dissipated as heat. For example, when you heat a beaker of water on a hot plate, the hot plate transfers some heat to the surrounding air instead of to the water. The hot plate also radiates heat to any other objects nearby, including you. All heating devices lose some heat to their surroundings.

Mechanical systems also dissipate energy to their surroundings. However, their heat losses may be less obvious than those in heating devices. Suppose you were using an electric motor to pump water from a well or river to irrigate a crop. You might find that the motor used 100 kJ of electrical energy for every 75 kJ of work done raising water up to the field. The other 25 kJ of energy is "missing."

Let's examine your pumping system. You can hear it running, so a bit of mechanical energy is being dissipated as sound. If the motor has been running for a while, it will be warm, perhaps even too hot to touch comfortably. Current flowing through the wires in a motor always produces some heat, and the friction between the moving parts generates heat as well. There is also friction between the moving parts in the pump and between the water and the walls of the pipe. The heat generated by this friction warms the water and pipe slightly, then dissipates into the surroundings. All of the "missing" input energy has been transformed into energy you cannot use.

In fact, all mechanical systems dissipate some energy, so their usable output energy is always less than their input energy.

*info***BIT**

Heat from Lighting

The heat from lights is not always wasted. During the winter, the heat from lighting helps keep buildings warm. In fact, some office buildings with extra insulation and specially designed ventilation systems can capture enough heat from lighting that they don't need furnaces.

UNDERSTANDING EFFICIENCY

The **efficiency** of a device is the ratio of the useful energy that comes out of a device to the total energy that went in. The more input energy that a device converts into useable output energy, the more efficient the device is. Efficiency is usually calculated as a percent:

$$\text{percent efficiency} = \frac{\text{joules of useful output}}{\text{joules of input energy}} \times 100$$

For example, let's look at the input and output energies of an ordinary incandescent light bulb, as shown in Figure 3.23. The percent efficiency of an incandescent light bulb is 5 J/100 J × 100 = 5. In other words, only 5% of the energy used by the bulb becomes light energy. Light bulbs transform the remaining 95% of their input energy into heat, which is often wasted. This heat is put to use in toy ovens where a single light bulb is used to bake a small cake.

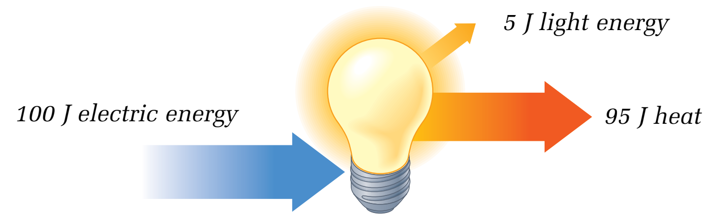


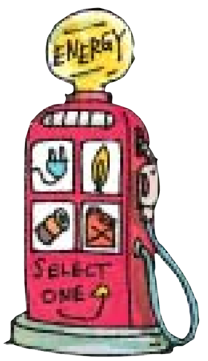
Figure 3.23 Most of the energy transformed by a light bulb is wasted.

SKILL PRACTICE

COMPARING INPUT AND OUTPUT ENERGIES

This table lists energy measurements from experiments on energy-converting devices. For each device, calculate the percent of its input energy that it converts to useful output energy. Which device is the most efficient? Which is the least efficient? What do you think causes the difference between the most and the least efficient?

Device	Input Energy	Useful Output Energy
Gasoline-powered sport utility vehicle	675 kJ	81 kJ
Gasoline-electric hybrid vehicle	675 kJ	195 kJ
Mid-efficiency natural-gas furnace	110 MJ	85 MJ
Electric baseboard heater	9.5 kJ	9.5 kJ
Alkaline dry cell	84.52 kJ	74.38 kJ
Fluorescent light	12.5 kJ	2.75 kJ
Incandescent light	780 J	31 J



ACTIVITY D-10

Problem Solving

KETTLE EFFICIENCY

Recognize a Need

In the world of advertising, products are promoted in a variety of ways to convince consumers to buy them. Sometimes claims that products can do certain things may seem false or exaggerated. A manufacturer can claim that its product is very efficient, but how can you be sure that their claim is true?

Materials & Equipment

- electric kettle
- timer
- thermometer
- 500-mL beaker
- graduated cylinder

The Problem

A consumer-product magazine wishes to determine if the efficiency claims for a particular electric kettle are true. You have been hired by the editor of the magazine to test the efficiency of the kettle.

Criteria for Success

- Design a procedure that will measure the amount of electrical energy consumed by the kettle while heating water (energy input).
- Design a procedure that will measure the amount of energy gained by the water (energy output).

  Note: The amount of energy gained by water can be calculated using the following formula. For water, 1 mL = 1 g.

  E = mass of water in grams $\times$ 4.19 $\times$ change in temperature in °C = energy in joules
- Carry out your procedure and calculate the efficiency of the electric kettle.

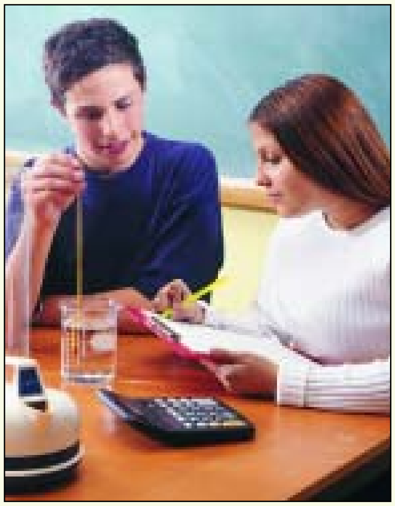


Figure 3.24 Determining the efficiency of an electric kettle

Caution!
Hot water and steam can burn.

Brainstorm Ideas

1 Write out the steps of a procedure and calculations you will perform that will allow you to successfully determine the efficiency of the kettle. (Hint: Do not allow the kettle to boil the water—it is very difficult to measure the heat gained by steam that has escaped.)

2 Have your procedure approved by the teacher.

Test and Evaluate

3 Conduct your procedure.

4 Record all the data you have collected and use it to calculate the efficiency of the kettle.

5 If your teacher has supplied other water-heating devices (such as a coffee maker or hot plate), use your procedure to calculate the efficiency of these devices as well.

6 List possible sources of error in your measurements. Estimate how accurate your calculations are.

Communicate

7 Report your efficiency results for the kettle (and any other devices you tested). Compare your results with those obtained by others in the class.

8 Would you make any changes to your procedure to increase the reliability of your results? Explain your answer.

9 Could your procedure be safely altered to determine the efficiency of other heating devices not meant for heating water, such as a blow dryer? Explain.

Figure 3.25 In a fluorescent tube, an arc through mercury vapour produces ultraviolet (UV) light. The tube's fluorescent coating absorbs the UV light and re-emits it as visible light.

Comparing Efficiencies

By comparing efficiencies of devices, we can judge both their energy cost and their environmental impact. For example, fluorescent lights are about four times more efficient than incandescent lights. Although fluorescent tubes also produce more heat than light, they transform about 20% of their input energy into light. Thus, they require much less energy to produce the same amount of light as incandescent bulbs.

Arc-discharge lamps are even more efficient. they produce light by passing an electric arc through a vapour of a metal such as mercury or sodium. Most cities use these high-efficiency lamps for streetlights.

New technologies are also improving the efficiency of motor vehicles. Hybrid gasoline-electric cars can be twice as efficient as gasoline-powered vehicles. The hybrid uses a smaller gasoline engine and an electric motor that provides extra power when needed. Sometimes the electric motor powers the car by itself. It even operates as a generator when the car is slowing down, producing electricity to recharge the batteries.

Check and Reflect

Key Concept Review

1. What is the difference between energy and power?
2. What energy conversions take place in an electric motor?
3. What is the law of conservation of energy?
4. A vehicle is only 15% efficient. What happened to the other 85%?
5. Compare the energy efficiency of incandescent and fluorescent bulbs.

Connect Your Understanding

6. You bake a potato in a 1200-W toaster oven for 25 min. How many joules of electricity did the toaster oven use? How many kilowatt hours did it use?
7. A colour TV draws 1.5 A when connected to a 120-V outlet. What is the power rating of the TV set?
8. A diesel truck produces 47.5 kJ of useful output energy from 125 kJ of diesel fuel. What is the truck's efficiency?
9. A small tractor is 12% efficient at producing useful output from input fuel. How many joules of input fuel energy will this tractor need to produce 1000 J of useful output?

Extend Your Understanding

10. Explain the advantage of operating a motor vehicle that is 20% efficient instead of one that is 10% efficient.
11. Two identical resistors connected in series use a total of 2 W of power. How much power would these resistors use if they were connected in parallel?

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Halogen Lamps

Halogen lamps produce about 50% more light than ordinary incandescent bulbs using the same amount of power. Find out more about halogen lamps. What are their advantages and disadvantages? Write a brief report providing advice to buyers of these lamps. Begin your search at www.pearsoned.ca/scienceinaction.

3.4 Reducing the Energy Wasted by Devices

Figure 3.26 An energy-efficient washing machine is designed to wash more clothes with less water.

Having to do laundry is a real drag. Spending your afternoon washing, drying, and folding laundry is bad enough, but how about paying too much for it, too? Appliances such as washing machines and dryers are designed for specific tasks and most perform them well. However, appliance designers did not always consider energy consumption. The washer in Figure 3.26 is a new design that uses much less energy than traditional washers. The energy-efficient design uses less electricity, washes more clothes per load, and uses less water. This reduces the energy needed to pump and heat water for laundry.

Every bit of electrical energy that flows into your home costs money. The energy that you use must be generated somewhere, and all generation and transmission methods affect the environment in some way. Lower energy demand means fewer power plants need to be built. This would avoid greater impact on the environment and major construction costs. These are good reasons to reduce energy consumption whenever possible.

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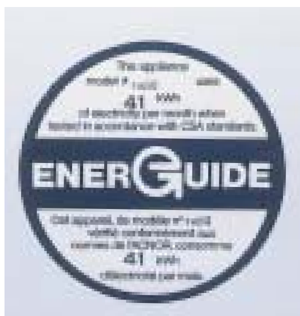
Overdrying

Millions of dollars of energy are wasted each year running clothes dryers to heat clothes that are already dry. Overdrying does nothing for your clothes. Overdrying creates static "cling" and contributes to shrinking and fabric damage. The solution? Cut down on drying time. Your clothes and electric bill will look a lot better!

GIVE IT A **TRY**

Shopping for Appliances



All large appliances sold in Canada must have an EnerGuide label that clearly states how much energy that appliance will use in a month of average use. This amount might not accurately represent how you will use the machine. However, it does allow you to compare the energy consumption of different brands and models.

Go to an appliance store and compare EnerGuide labels on electrical appliances such as refrigerators and dishwashers. Find out which models and brands use the most energy and which use the least.

Limits to Efficiency

Although it is possible for an electric heater to be 100% efficient in converting electricity to heat, devices that convert electricity to other forms of energy can never be 100% efficient. Any sort of movement generates a certain amount of thermal energy that is not useful output. Moving parts create friction within a system. Consider the many moving parts and points of friction in a typical combustion engine. Figure 3.27 shows just a few. This friction is one cause of energy loss in these engines. The largest energy losses result from hot exhaust and heat transferred to the cooling system.

Electric motors, like the one in Figure 3.28, have few moving parts. In some motors, the armature is the only moving part. Also, it is easy to put bearings at each end of the armature shaft to minimize the friction between the spinning shaft and the rest of the motor.

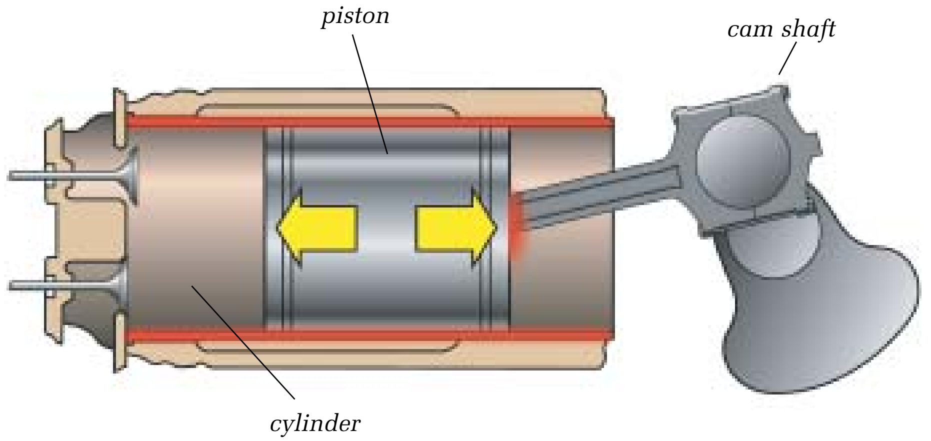


Figure 3.27 The pistons in a combustion engine move inside cylinders and create friction (indicated in red) as they stroke back-and-forth. Many other moving components in the engine create friction. Lubricants and component design can minimize the friction in these engines.

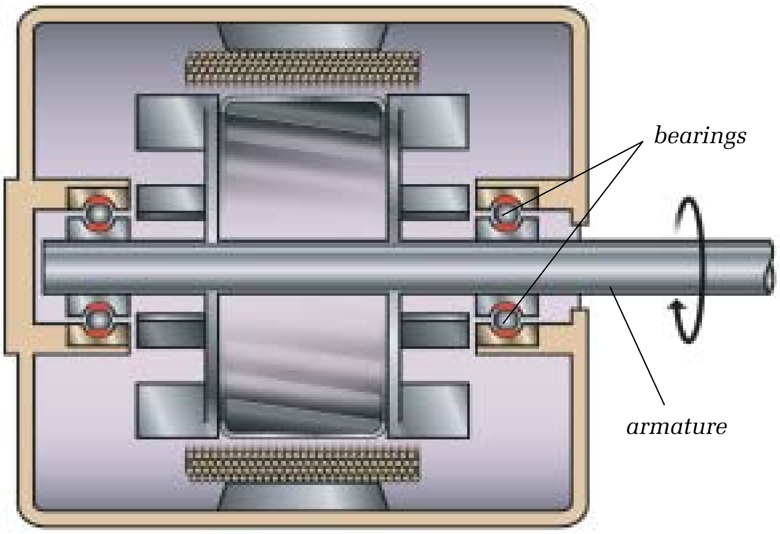


Figure 3.28 An electric motor has few moving parts and much less friction than a combustion engine.

ACTIVITY D-11

Decision Making

WHAT CAN WE DO TO INCREASE EFFICIENCY?

The Issue

Our day-to-day lives involve the use of many energy-converting devices. In what ways can you increase efficiency and reduce the amount of energy that you use?

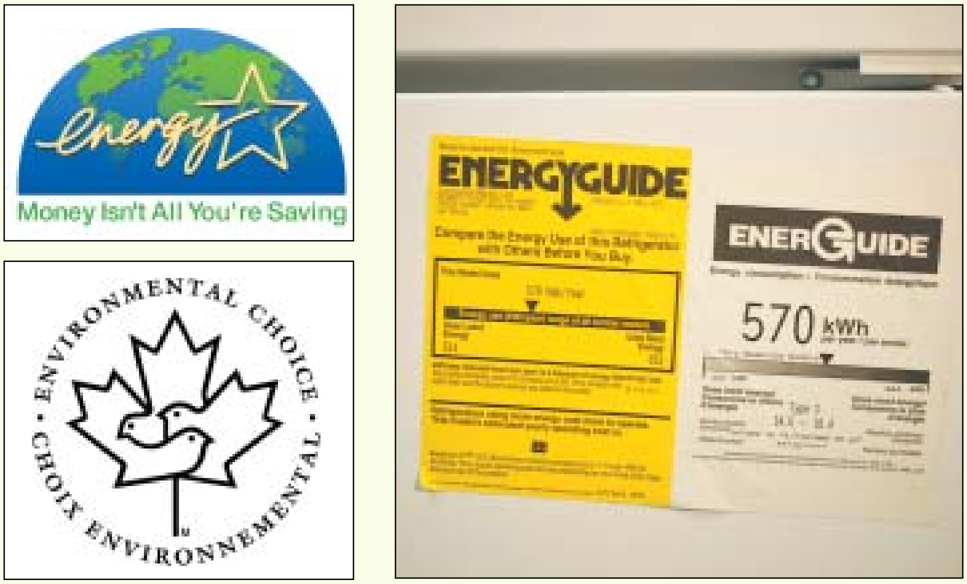


Figure 3.29 These labels can help you choose energy-efficient devices.

Background Information

Many energy choices are available to us in our daily lives. When choosing appliances, vehicles, or heating systems, we can look for more energy-efficient designs. Older equipment can be maintained, adjusted, modified, or replaced to increase efficiency. Don't forget to consider the energy it takes to make the changes you desire. For example, replacing a complete computer system for a gain in efficiency of 1% may not save energy because of the energy it takes to make a new computer.

1. Brainstorm a list of different ways you could increase the efficiency of the devices that you use daily. Also consider your purchase options when choosing new devices.
2. Research the energy savings impact of the items on your list.

Analyze and Evaluate

3. Choose the changes you would implement for maximum energy savings. Explain your reasons for the choices you have made.
4. Present your findings and recommendations for changes in a report to your classmates.
5. Compare your efficiency change recommendations with those of your classmates.
6. Are there any other changes you would recommend to Albertans as a group to increase the efficiency of energy usage?

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Cooking Tips

You can considerably reduce the amount of energy wasted in the kitchen by changing the way you use appliances. Research energy use for food preparation, and make a poster of "cooking tips" that can help reduce energy use in the kitchen. Begin your information search at www.pearsoned.ca/scienceinaction.

Increasing Efficiency

Increasing the efficiency of a device depends on its purpose. Many devices are made to convert electrical to mechanical energy, where the worst energy waste "offender" is friction. The easiest way to increase efficiency in these devices is to decrease friction as much as possible, for example, by using improved bearings and lubricants.

In devices where heat is produced, the major concern is heat loss from the system. Heat that escapes is waste heat which is not performing its task. Adding more insulation around the oven in a stove reduces the amount of heat escaping through the walls of the oven, so you will need less energy to keep the oven hot. Similarly, improving the insulation in the sides of the refrigerator reduces the amount of heat that transfers into the fridge. You need less energy to keep the fridge cold.

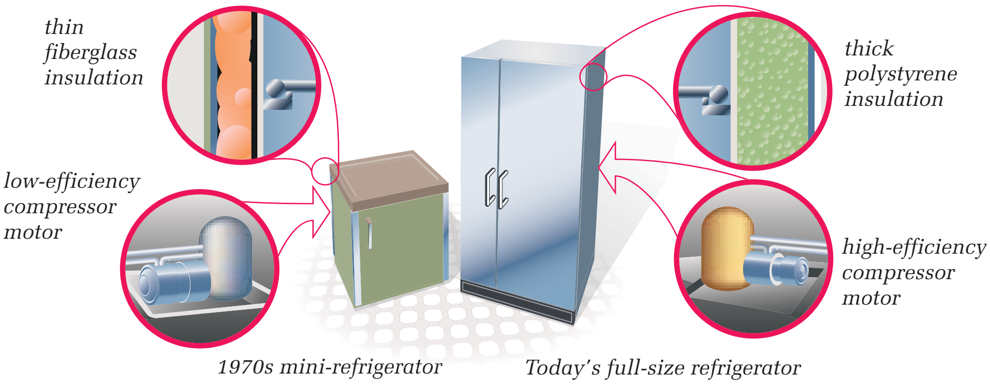


Figure 3.30 In the last 25 years, refrigerator efficiency has increased approximately 300%. The energy used to run a mini-refrigerator in the 1970s can run a full-size refrigerator today.

Check and Reflect

Key Concept Review

1. Give two reasons for reducing energy waste.
2. What is the purpose of the EnerGuide label on appliances?
3. How can a more efficient appliance benefit the environment?
4. Why are electric motors more efficient than combustion engines?

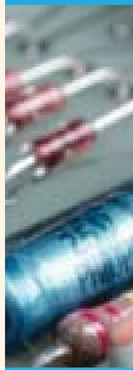
Connect Your Understanding

5. What causes most energy loss in devices designed to produce mechanical energy? What can be done to avoid it?
6. Is it always a good idea to discard low-efficiency devices? Explain your answer.
7. Explain how you might change the design of a typical gasoline-powered lawn mower to increase its efficiency.

Extend Your Understanding

8. An electric-assist bicycle has a rechargeable battery and electric motor that can be used instead of pedalling. What type of design features and maintenance suggestions would you recommend to keep an electric-assist bicycle operating at peak efficiency?

Section Review



Assess Your Learning

Key Concept Review

1. You overhear someone say, "An electric heater does the opposite of a thermocouple." Is this an accurate statement? Explain your answer.
2. What is the function of the brushes in an electric motor?
3. What is the function of the permanent magnets in an electric motor?
4. What energy transformations take place in the following devices: a dishwasher, a DVD player, a stereo speaker, and a hot-glue gun?

Connect Your Understanding

5. Two sisters own stereos. Joleen has a 40-W mini-system. Julianna has a large 120-W system. Is it possible for Julianna's system to use less energy in a month than Joleen's? Explain your answer.
6. A computer plugged into a 120-V outlet draws 3.0 A of current. How much power is the computer using?
7. A chemical laser in a research laboratory can fire for 10 s with a power of up to 10 MW. What is the maximum energy this laser would use when it fires?
8. A 330-W hot plate produces 38 kJ of thermal energy while operating for 2 min. What is the efficiency of this device?

Extend Your Understanding

9. You have designed and built an electric golf cart, but it goes only halfway around the course before running out of power. Describe modifications you could make to improve the range of your golf cart.
10. Your brother replaces the electric razor he purchased last year with a new, more energy-efficient model in order to save on his power bill. What does energy-efficient mean? Was this razor a wise purchase?

Focus On Science and Technology

The goal of technology is to provide solutions to practical problems. One of the practical problems with using electrical technologies is how to improve efficiencies. Think about what you learned in this section.

1. Give two examples of practical problems related to efficiency that you read about in this section.
2. How were technologies used to solve these problems?
3. What knowledge from a related scientific field would a scientist or engineer need to develop these technologies?

4.0 The use of electrical energy affects society and the environment.

Key Concepts

In this section, you will learn about the following key concepts:

- energy transformation
- energy transmission
- generation of electrical energy
- energy storage
- renewable and nonrenewable energy

Learning Outcomes

When you have completed this section, you will be able to:

- identify and evaluate alternative sources of electrical energy, including oil, gas, coal, biomass, wind, waves, and batteries
- describe the by-products of electrical generation and their impacts on the environment
- identify example uses of electrical technologies and evaluate technologies in terms of benefits and impacts
- identify concerns regarding conservation of energy resources
- apply the concept of conservation of energy
- evaluate means for improving the sustainability of energy use

The world has a huge appetite for electrical power, but how do we meet this growing demand? Technology is not a limitation in generating large amounts of power or in getting it to where it is needed. A power-plant generator like the one above can produce up to a million kilowatts of electrical power.

The total output of all the electrical generators in Canada is more than 100 million kilowatts. All the world's power-generating facilities together produce about 3 billion kilowatts. Every second, enough electrical energy is produced to light a 100-W bulb for 951 years. In this section, you will learn more about the generation of electricity from different energy sources. You will also learn about the impact that electrical generation can have on the environment. You will consider how to balance the benefits of using electricity with the need to conserve energy resources.

For Web links relating to 4.0, visit www.pearsoned.ca/scienceinaction

4.1 Electrical Energy Sources and Alternatives

Worldwide, about 65% of all electric power is generated by burning oil, coal, or natural gas. These fuels are often called **fossil fuels** because they formed from the decomposition of prehistoric plants and animals.

Most of the fossil fuel used in power plants is coal. Coal is a reasonable choice in areas like Alberta that have large and easy-to-excavate deposits. However, mining coal or tapping deposits of oil or natural gas is only the first step toward generating electricity from fossil fuels.

Using Heat to Generate Electricity

How do we use coal to turn a generator? The coal is powdered, then blown into a combustion chamber and burned to release heat, as shown in Figure 4.1. The heat boils water and superheats the resulting steam to a high temperature and pressure. This high-pressure steam drives a large **turbine**. The turbine is a long shaft with many fan blades. Steam striking the blades turns the turbine. The turbine shaft rotates large electromagnetic coils in the generator to produce electricity. Oil or natural gas can be burned in the combustion chamber instead of coal.

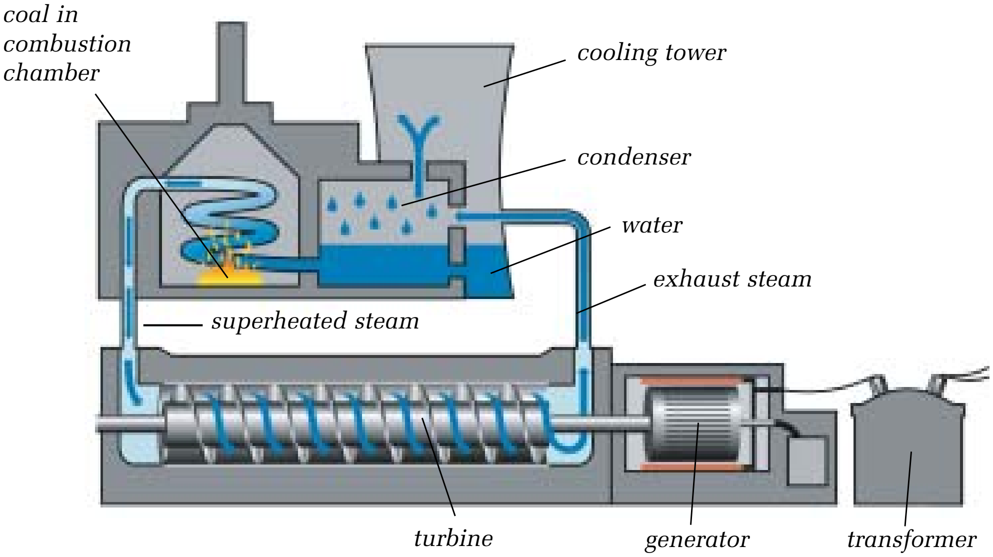


Figure 4.1 Coal-fired generating plant

Burning fossil fuels is not the only way to provide heat for a steam-powered generator. In Ontario, the United States, and parts of Europe, nuclear reactors are used extensively to produce steam in power plants. In a nuclear reactor, atoms of a heavy element, usually uranium, are split in a chain reaction. This splitting, known as **nuclear fission**, releases an enormous amount of energy.

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Packed with Energy!
Coal contains a great deal of stored energy. Burning a single kilogram of Alberta coal will produce about 27 MJ of thermal energy. That's enough to boil about a third of a bathtub full of water.

Figure 4.2 Geothermal energy heats this hot spring.

Heat from Earth's core can also be used to generate electricity. In several places in the world, hot water and steam naturally come to the surface after having been heated by hot rock within Earth's crust. This is called **geothermal energy**. The steam is channelled through pipes and used to drive turbines. In some applications, water is injected back into the ground to take full advantage of the hot geothermal energy source.

Another interesting source of fuel is **biomass**. Biomass could accurately be described as garbage, but it's a particular type of garbage. Most cities and towns bury their biodegradable waste in landfills. When it decomposes, it produces combustible gases that can be collected and used as fuel for steam-driven generators. Yard clippings, dead trees, unused crops, and food-based garbage can also be burned to produce steam.

Some industrial processes, such as glass manufacturing, use very high temperature furnaces. The waste heat from the manufacturing process can be used to produce steam. This steam can then be used to drive a turbine to generate electricity. Fuel is burned in the manufacturing process to produce the heat in the first place, but no new fuel is needed to produce the electricity. Making double use of energy in this way is called **cogeneration**.

Using Water Power to Generate Electricity

About 20% of the world's electricity is generated by hydro-electric power plants. These plants capture the energy of falling water. Some hydro-electric plants, like the ones at Niagara Falls, use the flow from a waterfall, but most use a dam built across a river to store water in a reservoir. Water is directed through a channel called a penstock to a large paddle-covered turbine. The rushing water spins the turbine, which is connected to a generator in the same way as a steam-driven turbine.

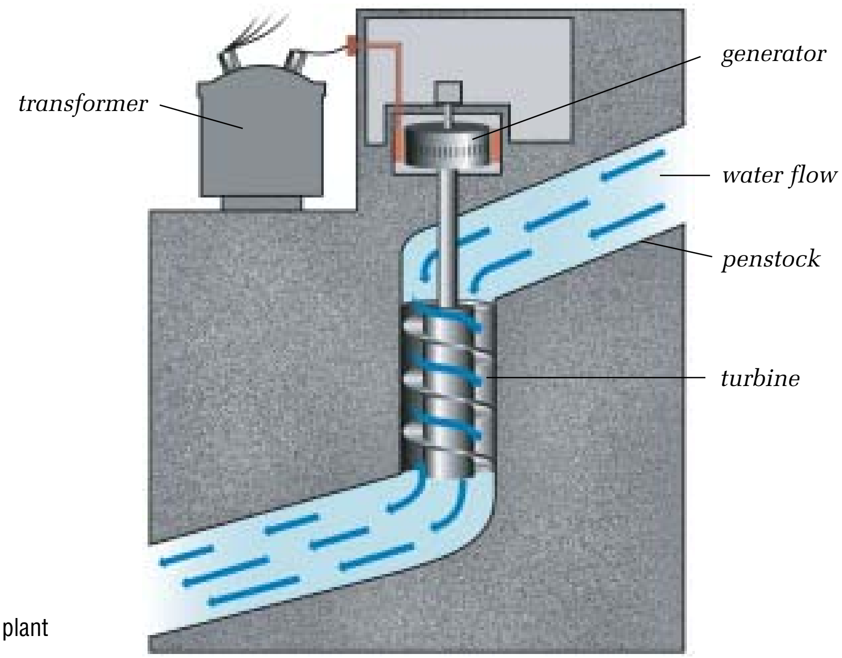


Figure 4.3 Hydro-electric plant

Alternative Energy Sources

Tides

Moving water from tides can also power turbines that run generators. Tidal power stations operate rather simply. When the tide comes in, the water is trapped in a reservoir and then let out past turbines. There are not many tidal power stations in the world because of the difficulty of finding suitable locations. One is located in Nova Scotia at the mouth of the Annapolis River. It takes advantage of the large tides in the Bay of Fundy. Waves can be used to generate electricity too. In one type of wave-power generating station, the up-and-down movement of the water drives a piston connected to a generator.

Figure 4.4 Windmills used to generate electricity at Cowley, Alberta

Wind

Wind energy can be harnessed to turn a shaft. For centuries, windmills used sails on the ends of shafts to provide power to grind grain and pump water. Modern windmills use more efficient designs with propeller-shaped blades. The amount of electricity a single windmill can generate is limited, but a number of wind-powered generators can be connected together in "wind farms" to produce larger amounts of electrical energy.

Sunlight

In 1839, French scientist Alexandre Edmond Becquerel soaked two metal plates in an electricity-conducting solution. When he exposed one of the plates to sunlight, he was able to detect a small voltage. Becquerel had discovered the photovoltaic effect and invented the first solar cell. Unfortunately, the voltage from his invention was too small to be useful as a source of power. In the 1950s, scientists began using silicon to make solar cells. Silicon-based solar cells are much more efficient at producing current. It is now common to find solar modules (several cells connected together) and arrays (several modules) used to power everything from calculators to spacecraft.

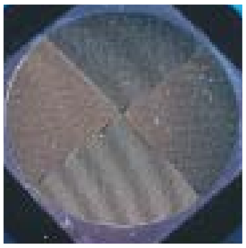
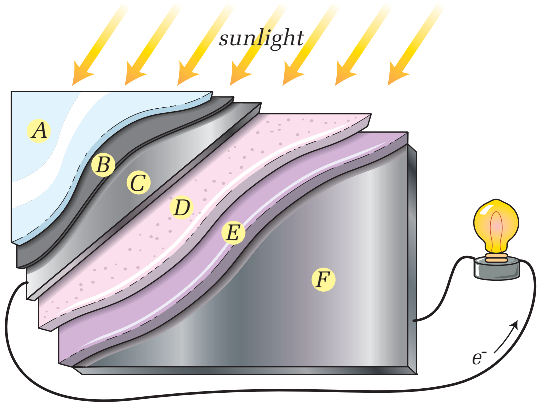


Figure 4.5 The International Space Station uses 2500 m^2 of solar cells to generate its electricity.



A Protective cover glass
B Antireflective coating to let light in and trap it
C Metal contact grid to collect electrons for circuit
D Silicon layer to release electrons
E Silicon layer to absorb electrons
F Metal contact grid to collect electrons from circuit

Figure 4.6 A solar cell consists of several layers. At the heart of the cell are two specially treated silicon layers that create current when in sunlight.

Batteries

Batteries are a convenient source of electricity for portable devices. However, large banks of batteries are rarely used because they are expensive and bulky. For example, an alkaline D-cell would light a 100-W light bulb for about 15 min. You would need a room full of batteries to run all the appliances in your house. Obviously, batteries are not practical for lighting whole cities.

Rechargeable batteries are widely used to provide backup power for emergency lights and computer systems. However, these batteries produce electricity only after they have been charged using electricity from an external source. Since rechargeable batteries are never 100% efficient, they actually use more electricity than they produce.

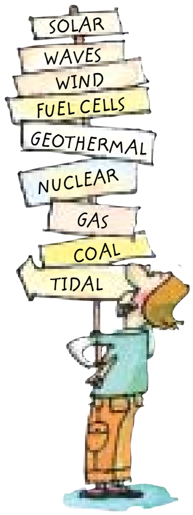
Recently, much research has been done to develop **fuel cells**. A fuel cell generates electricity directly from a chemical reaction with a fuel such as hydrogen. The hydrogen comes from sources such as gasoline or alcohol. More fuel is added as electricity is produced, so the cell is not used up as an ordinary cell would be. Larger fuel cells can be used to power electric vehicles. Smaller ones are being developed for use with portable devices such as laptop computers.

GIVE IT A **TRY**

ENERGY NEWS

Now that you've learned a bit about Earth's energy sources, it's time to dig deeper. All energy sources have advantages and disadvantages. Your task as a reporter is to find out more about two energy sources, and compare them. Compare any two of the following:

- wind
- nuclear
- geothermal
- waves
- solar
- natural gas
- fuel cells
- coal
- tidal
- biomass



Use your library or the Internet to find out more. If possible, interview an expert. On the Internet, begin your search at www.pearsoned.ca/scienceinaction.

- Compare as many factors as possible. For example, you could consider availability, cost, sustainability, environmental impact, applications (what the source can be used for), and safety.
- Prepare your findings in a report. In the spirit of "alternative" energy sources, consider alternative methods for presenting your report. You might design a poster, Web page, or a multi-media presentation. You could write an essay or make a videotape.

Activity D-12

Problem Solving

Harness the Wind

Recognize a Need

You have been contracted to design and build a windmill. It will be used in an exposed area that is windy all the time, although the strength of the wind varies. There are low winds lasting for several days but also periods of intense wind. Your client wants to use these winds to generate electricity.

Materials & Equipment

- a fan to test your windmill
- small electric motor with pulley
- connecting wires
- galvanometer (or milli-ammeter)
- materials to build your model

The Problem

You must design a windmill that operates well in both low and high winds.

Criteria for Success

You must build a working model that meets the following criteria:

- Your model must be free-standing, although it can be anchored to the surface it sits on (for example, taped to a desk).
- The turning shaft of your windmill must be attached to the armature of a small electric motor so that when the windmill shaft turns, the motor armature turns. Although not specifically designed for the task, the electric motor will serve as a direct current generator.
- Your windmill must produce a detectable current. This can be determined by connecting the galvanometer to the leads of the generator (small motor).
- Your windmill must function in a stable manner when tested with a fan held at different distances to mimic low and high winds. Your teacher may give you more detailed criteria for testing with a specific fan.

Figure 4.7 Designing a windmill

Brainstorm Ideas

TOOLBOX

1 With your team, brainstorm possible solutions. Once you have several solutions, choose the one you think will work the best to meet the criteria above. You may want to read Toolbox 3 to help you with the problem-solving process.

Build a Prototype

2 Create a plan of how you will build your windmill. Include a diagram and a list of the materials that you will need. Show your plan to your teacher for approval.

3 Assemble your materials and build your windmill. Remember that you may need to modify or change your design as your windmill progresses. Make sure to note any changes on the original design you submitted to your teacher.

Test and Evaluate

4 When you have built your windmill, test it to see if it meets the Criteria for Success. Identify any practical problems with your device. You may need to make changes to correct problems, and then repeat the tests.

Communicate

5 How well did your windmill function under varying wind conditions? If your windmill functioned better under one wind condition, explain why.

6 Evaluate your design for the factors listed below. For each factor, describe how well you think your device would work if it were built to full size.
a) reliability b) safety c) current generating efficiency

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Fusion

Fusion reactions occur in the Sun and provide all the energy for life on Earth. Scientists are investigating the potential of fusion as a limitless, pollution-free source of energy. Find out more about fusion. Make a chart comparing fusion with the nuclear energy we use today. Start your information search at www.pearsoned.ca/scienceinaction.

Renewable and Nonrenewable Energy

Alberta has substantial coal reserves, enough to last over two hundred years at current rates of consumption. However, coal is a **nonrenewable resource**—it cannot be replaced as it is used up. Alberta's other fossil fuel resources are also nonrenewable. Crude oil (petroleum), and natural gas will eventually run out. When the supplies of these fossil fuels are gone, they are gone forever.

In contrast, **renewable resources** can be renewed or replenished naturally in relatively short periods of time. Some are continually replenished. Wind energy, tidal energy, solar energy, geothermal energy, and biomass are resources that naturally renew themselves, so they can last forever. If tree harvesting is managed carefully, replanting can ensure that wood supplies for energy can last indefinitely. However, if wood is used faster than trees can be grown, then the renewable resource cannot meet energy needs indefinitely.

Check and Reflect

Key Concept Review

1. Describe the turbine's role in an electric generator.
2. Is it correct to say that the majority of the world's electrical demands are met with hydro-electric generators? Explain why or why not.
3. What is the difference between a renewable and a nonrenewable resource?
4. Look at Figure 4.6 on page 347. Describe how a solar cell produces electricity.
5. What is cogeneration? Give one example.

Connect Your Understanding

6. How can a river be used to produce electricity?
7. What do nuclear power plants and coal-fired power plants have in common?
8. What is biomass? How can it be used to create electricity?
9. Make a chart summarizing how tides, geothermal sources, sunlight, and wind can be used to produce energy.

Extend Your Understanding

10. Why don't power stations use batteries to generate electricity?
11. Residents of a remote community decide to use wood as their primary energy source. All the trees nearby are cut down and stockpiled for use in home heating and heating the boiler of the community's electrical generator.
    a) Is the community's energy source guaranteed to last indefinitely? Explain.
    b) What recommendations would you make to ensure that this community has a reliable long-term energy supply?

4.2 Electricity and the Environment

Every method of generating electricity affects the environment. Some methods create undesirable by-products. These by-products have negative effects on human health and the environment.

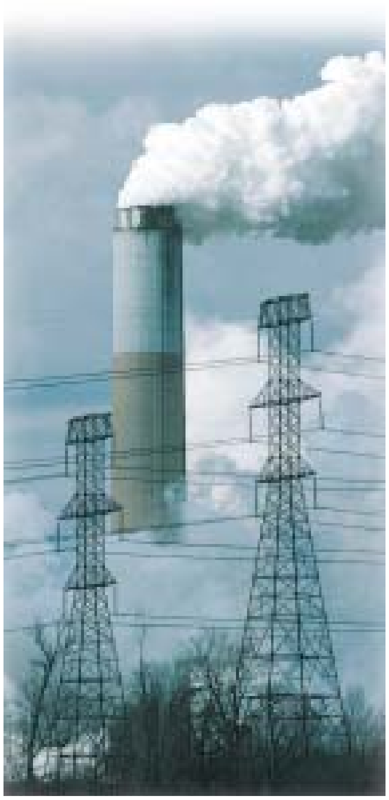

Figure 4.8 Burning fossil fuels produces air pollution.

Air Pollution

The burning of fossil fuels results in the release into the atmosphere of many problem-causing substances. For example, when coal burns, it leaves behind a powdery ash. Some of this ash is carried up the smokestack of the power plant and escapes into the atmosphere. This airborne ash is often referred to as **fly ash**. In Canada, air pollution produced by coal-burning plants has been reduced over the last 30 years by improved methods of cleaning the coal and capturing the fly ash. However, considerable amounts of fly ash still escape. This is a concern because the fly ash contains small amounts of mercury, a poisonous metal that can damage the nervous system.

Many other molecules are released into the air when coal is burned. Some of the most harmful are sulfur dioxide ($SO_{2(g)}$), nitrogen oxides ($NO_{x(g)}$), and carbon dioxide ($CO_{2(g)}$). Sulfur dioxide causes acid rain and contributes to air pollution. Nitrogen oxides are major causes of air pollution. Carbon dioxide in the atmosphere has been identified as a cause of global warming, which leads to climate change. You can learn more about these chemicals and their effects in Unit C: Environmental Chemistry.

Other Environmental Effects

Figure 4.9 Strip-mining coal

Much of the coal used in power plants comes from strip mines. Strip-mining techniques are used when deposits are near the surface. Bulldozers clear the soil, and sometimes explosives are used to help clear any rock above the deposit. Large scoops collect the coal and load it into trucks that take the coal away for further processing. This type of mining removes all plants and animals from large areas of land. Although the land can be reclaimed by replacing the soil, the original natural environment usually is not fully restored.

Oil and gas wells can also affect the area surrounding them. Some deposits contain poisonous gases. Measures must be taken to prevent the release of these gases into the environment. Concentrations of chemicals in the environment around wells and plants are monitored for safety.

In electricity generation, steam turbines often release a great deal of warm water into nearby lakes and rivers. The resulting increase in water temperature alters the local freshwater ecology and can sometimes kill fish.

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Nuclear Waste Storage
Radioactive waste from nuclear power plants requires long-term storage. Canada's plans for storing this waste include placing corrosion-resistant containers in vaults deep within the Canadian Shield. These vaults will be 500 to 1000 m deep and will likely be in Ontario.

The mines and refineries that produce fuel for nuclear reactors can also damage the environment. The reactors create radioactive wastes that remain dangerous for thousands of years. Hydro-electric plants produce no pollutants, but their dams flood many hectares of land and alter the ecosystems of rivers. Wind farms and solar cell arrays require large tracts of land to generate practical amounts of energy. Also, the process for making solar cells creates some chemical pollution. The steam from geothermal plants produces a small amount of pollution. Generators using tidal or wave energy may disrupt the habitat for fish and other marine life. However, the "green" sources of energy—especially wind, tide, and geothermal—harm the environment much less than fossil fuels do.

Conserving Energy and Nonrenewable Resources

We know that reserves of oil and gas are decreasing, but it is likely that nonrenewable fossil-fuel supplies will last for your lifetime. So why bother trying to conserve energy? If demand for energy decreases, there is a lower demand for the resources that fuel electrical generating plants. Those pollution-producing plants that are already in operation would not need to operate at full capacity and may even be able to cease operation. The obvious benefit is less pollution, which is a good reason to try to use less electricity whenever possible. When your actions lead to a lower demand for natural resources, you are practising energy conservation.

You may not have to worry about fossil fuels running out in your lifetime. However, even temporary shortages can cause hardship and big price jumps. When fuel prices skyrocket, poorer countries cannot afford the energy they need.

Suppose you want to conserve fossil fuels and reduce pollution. You consider buying an electric car instead of one with a gasoline engine, but you know you have to look at more than just engine efficiency. Electric cars reduce the need for gasoline, which comes from oil. Burning less gasoline conserves oil reserves and reduces pollution. The electric car, however, must get electricity from somewhere for its rechargeable batteries. If a coal-fired plant supplies this electricity, you may not be saving fossil fuels or reducing pollution overall. However, if a hydro-electric plant or windmill farm supplies the electricity, fossil fuels will be conserved and pollution will decrease. Both personal and societal decisions must be taken into account when considering conservation.

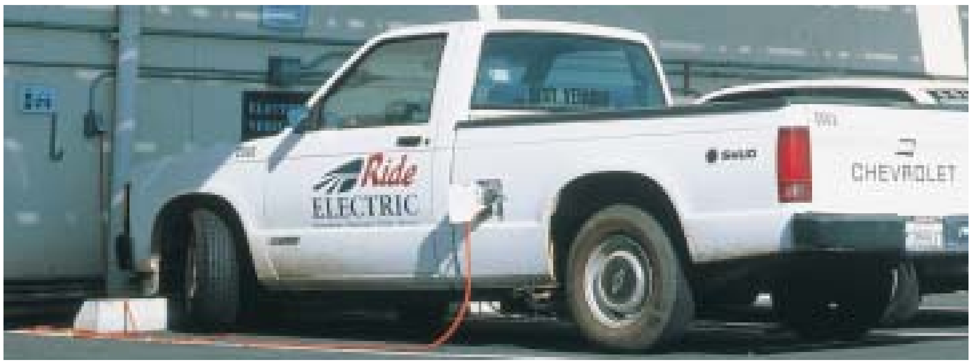


Figure 4.10 Does an electric vehicle conserve energy resources?

A Sustainable Future

Conserving energy means moving toward sustainability. **Sustainability** means using resources at a rate that can be maintained indefinitely. If we do not achieve *sustainable* energy use, future generations may not be able to support themselves. A sustainable approach sometimes requires a different way of developing resources. In the past, mineral and hydrocarbon deposits were used up as quickly as possible to earn money and satisfy consumer demand. We need to use our resources in a way that makes them available over a longer period. Sustainability may also mean no longer using nonrenewable resources because they cannot be maintained indefinitely.

We may never be able to achieve complete sustainability, but the decisions we make personally and as a society can move us closer to this goal. An example of a personal decision would be to take public transportation rather than driving your own vehicle. This saves fuel and reduces pollution. Decisions made with sustainability in mind sometimes involve compromise—a bus may not be as convenient as your own car. An example of a societal decision related to sustainability is the use of low wattage street lights. Some cities have installed these lights to reduce electricity consumption and light pollution. In this case, the drawback is that streets may not be as brightly lit.

reSEARCH

Acid Mine Drainage

The environmental effects of using coal start with its removal from the ground. The water that flows through mines and coal storage areas can become acidic. It may also contain dissolved metals. Research acid mine drainage. Prepare a brief report on its environmental effects and what is being done to reduce those effects. Start your search at www.pearsoned.ca/scienceinaction.

Check and Reflect

Key Concept Review

1. How can oil wells affect the environment?
2. Do nuclear power plants produce by-products? If so, are they harmful?
3. What is fly ash? Why is it an environmental concern?
4. Explain why you agree or disagree with the following statement. *"Green" sources of energy such as solar and wind power have no environmental impact.*

Connect Your Understanding

5. What is the difference between energy conservation and energy sustainability?
6. Does replacing the soil removed by strip-mining restore the environment? Explain your answer.
7. Explain how each of the following actions affect energy sustainability:
   a) replacing a coal-fired power plant with several fields of solar arrays
   b) choosing a new refrigerator that is high efficiency
   c) carpooling with friends to drive to work
   d) replacing the incandescent bulbs in your home with compact fluorescent bulbs

Extend Your Understanding

8. A friend brags to you about her new electric car that uses rechargeable batteries as an energy source. She says, "My new car doesn't have an internal combustion engine, so no fossil fuels are needed to provide energy for it." Is this an accurate statement? Explain your answer.
9. In 1906, many steam-powered cars were on the roads. The record for the fastest steam car was approximately 206 km/h. A British team is now working to build a modern steam car that it hopes will travel over 300 km/h. While this car will be fast, will it conserve energy? Explain.

info BIT

Less Luggage

A business traveller used to have to carry a cellular telephone, an organizer, and a laptop computer. Now digital wireless technologies let people on the road phone their offices and clients, manage their contact information and appointments, and connect to the Internet, all with a device small enough to fit in a pocket!

4.3 Electrical Technology and Society

Figure 4.11 Electrical technology lets us communicate at the speed of light.

In 1844, the first electrical communication took place with the help of Samuel Morse's invention, the telegraph, shown in Figure 4.11. Morse developed a code of dots and dashes (short and long electrical signals) to send messages down wires from one city to another. Today, electrical technologies continue to make fast and efficient communication possible. With the rapid development of personal computers in the 1980s and the Internet in the 1990s, we now have the ability to collect and transmit vast amounts of information.

Benefits of Electrical Technologies

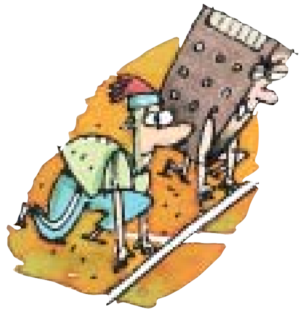
It would be a major understatement to say that electrical technologies have improved our standard of living. Most electrical devices and inventions came out of a desire for speed or convenience. Consider, for example, how the task of doing laundry has changed. Before the invention of the modern washing machine, it could take a whole day of hard work to complete the washing for an average family. Now, machines do the washing, rinsing, and drying, freeing people to do other things. In a similar way, many electronic devices help us to complete a variety of tasks more quickly and efficiently, and give us more time for other activities.

GIVE IT A TRY

NUMBER RACE

You will compare the time taken to do a calculation without and with a calculator.

Write an arithmetic problem requiring the addition and subtraction of 10 three-digit numbers. Trade your problem with someone else, then time each other on how long it takes to do the calculations the good old-fashioned way—by hand. Now time each other doing the calculations using an electronic calculator.



- In what way is an electronic device better for doing calculations? In what way is it worse?
- Design a similar test for processing words instead of numbers.

DRAWBACKS OF ELECTRICAL TECHNOLOGIES

More technology means that more resources are needed to manufacture and operate devices. This can make sustainability more difficult to achieve. And as technology progresses, it leaves behind obsolete devices. These devices are usually discarded as waste, so they add to problems with solid waste disposal. Some technologies may also be too expensive for developing countries to adopt. This can have the effect of isolating people and excluding them from the benefits of technological advancement.

COMPUTERS AND INFORMATION

If you are looking for a device that has brought radical changes in speed and convenience, look no further than the computer. Computers have revolutionized the way we accomplish many tasks, including writing, calculations, and communication. Computers convert all information—even audio and video signals—into numbers and then perform calculations with the numbers. Computers use **binary numbers**, that is, numbers with just ones and zeroes. These numbers correspond to the on and off states of the millions of tiny transistors in the microcircuits. Because the data is converted to strings of digits, this method of storing and transmitting information is often referred to as a digital technology.

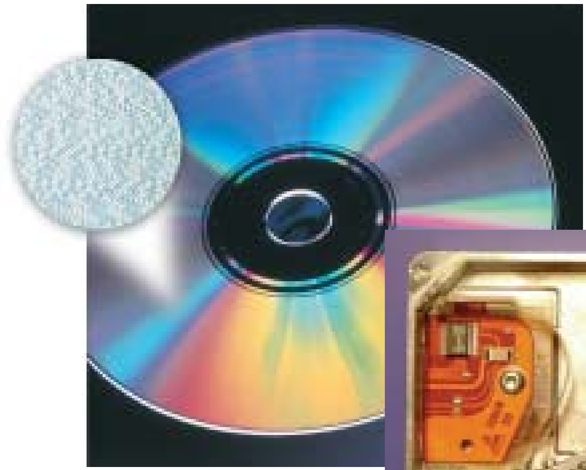
*info***BIT**

Programming Pioneer

By 1952, Grace Hopper (1906-1992) had developed a working compiler, a program that translates English words into the special codes needed to run computers. Such compilers are the key to all the high-level computer languages we use today. Hopper also co-authored COBOL, a widely used programming language for businesses. The term "computer bug" originated in 1951 when Hopper found a moth jamming a relay in one of the first large-scale computers.

Electricity and Computers

Different techniques can be used to store and transmit information, but all of them take advantage of electrical current in one way or another. For example, a compact disc (CD) player scans a CD with a laser. Tiny pits stamped into the surface of the shiny disc cause the laser light to be reflected in pulses. A photodetector converts the light pulses into electrical pulses. This produces a digital signal with exactly the same sequence of ones and zeroes as the master recording used to make the CD.



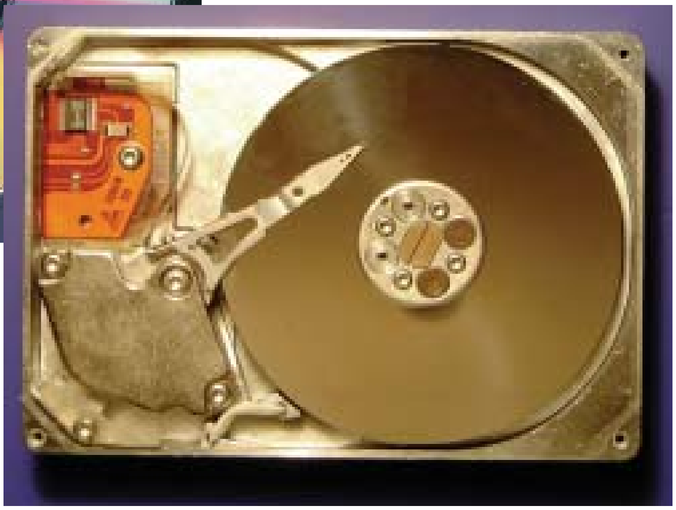


Figure 4.12 Compact discs (CDs) and computer hard drives both store digital information, although in different ways.

A hard drive in a computer also uses pulses of electricity to record and transmit information. In a hard drive, a highly polished aluminum or glass disk coated with a thin layer of magnetic material rotates at speeds of up to 300 km/h. Electrical pulses are sent to an arm with read/write heads. These tiny electromagnetic coils magnetize spots on the spinning disk. When a head reads the disk, the magnetized spots induce pulses of current in the electromagnetic coil. This reproduces the ones and zeroes in the original signal. When the heads are writing, they respond to electrical signals from the computer's processor. When the heads read the disk, the hard drive sends an electrical signal to the processor. Electrical signals control all the functions of a computer, including the images on the screen and the sounds from the speakers. If these electrical signals can control your computer, could signals also be sent to control a remote computer? Such signals are the key to networking and the Internet.

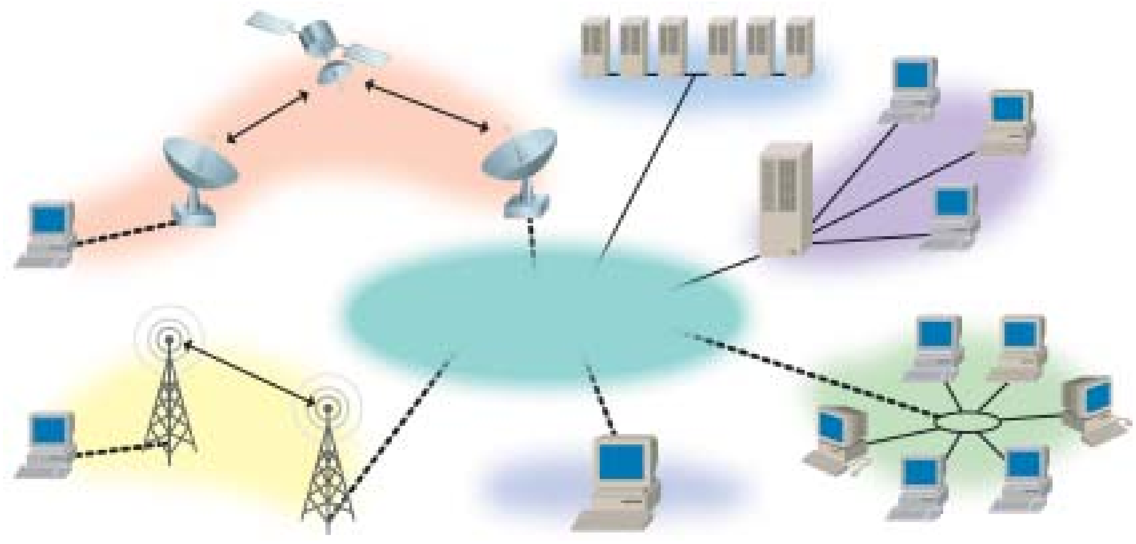


Figure 4.13 Electrical signals sent between computers around the world make internetworking possible.

Electrical Transmission of Information

There is little doubt that electronic storage of information is a huge benefit to society. Information is cheaper to store, easier to find, and much more compact. For example, a single digital video disc (DVD) can store more information than a whole set of encyclopedias. Electronic media can store audio and video, as well as text, which often makes information easier to understand and more entertaining. Hard drives in personal computers make storage and retrieval of large amounts of information fast and convenient. Thousands of hard drives in servers connected to the Internet all around the world put huge amounts of information at your fingertips.

But there are some concerns about the explosion of information and electronic technology. One issue is access to technology. Some countries are too poor to establish the infrastructure necessary to connect computers and transmit information.

Another issue is privacy. Data transmission is not always secure. Files, such as financial and personal information, sometimes fall into the wrong hands. "Hackers" attempt to break into networks either to steal information or to cause damage for the sake of challenge, or for no reason at all.

*re*SEARCH

Encryption

Ever since the transfer of information became possible, people have been developing ways to protect it. Such protection is especially important for the transfer of financial information such as credit-card numbers over the Internet. Find out more about encryption. Use an example to show how encryption is done and how it is used. Start your information search at www.pearsoned.ca/scienceinaction.

Can you trust all the information that you find over the Internet? With huge volumes of information stored worldwide, some of it will be wrong or misleading. Most people have good intentions, but some will post "facts" that they have not checked properly. Others may deliberately send out wrong information.

Another concern is "information overload." With greater and greater capacity to store information, it becomes increasingly more difficult to find the particular piece of information that you need.

Search engines were developed to help sort through the vast amount of unorganized information on the Internet. A search engine is an application that searches the Internet for keywords or phrases that you enter in a query field. Internet sites that match your keywords are then reported back to you.

However, search engines work in different ways and may not be as helpful as you might expect. For example, some search engines report only results from sites on the Internet that have been manually entered in a database. Useful sites that have not been entered in the database are not reported. Other search engines report only the most-visited sites on the Internet; that is, the most popular sites. Because of this, a more useful, less popular site may be overlooked. This explains why using different search engines may provide different results for the same keywords or phrases that you are searching for.

Check and Reflect

Key Concept Review

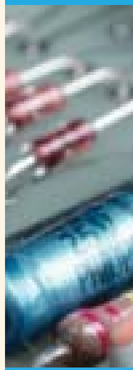
1. Name two benefits of electrical technologies.
2. What is special about a "binary" number?
3. Explain some of the drawbacks of information technology.
4. a) In what form is computer information stored?
   b) In what form is it transmitted?

Connect Your Understanding

5. Why could more technology make sustainability more difficult?
6. Explain how it is possible for your home computer to connect to and retrieve information from a computer in another country.
7. How is an Internet server computer different from a home computer? How is it the same?

Extend Your Understanding

8. What does electricity have to do with the storage of information on a computer?
9. A classmate explains to you that his mother is treating her own medical condition with health advice she found while using the Internet. What, if any, concerns might you have about this?



Assess Your Learning

Key Concept Review

1. What is sustainability? Give one example.
2. Describe the advantages and disadvantages of using coal as an energy source.
3. Briefly describe geothermal and tidal methods of generating electricity.
4. Describe some of the ways that computers can connect with each other.
5. Why are coal, natural gas, and oil referred to as "fossil" fuels?

Connect Your Understanding

6. Use a Venn diagram to compare the generation of electricity using coal with hydro-electricity generation. How are they similar? How are they different?
7. A group of Alberta farmers forms a co-operative group and builds a factory that turns grain into alcohol as a fuel for generators and cars. Would this energy source be renewable or nonrenewable? Explain.
8. Do advances in computer technology benefit everyone in the world equally? Explain your answer.

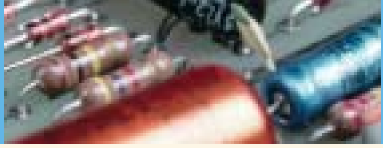
Extend Your Understanding

9. *A nuclear power plant provides energy using a radioactive source, so a turbine is not needed.* Explain why you agree or disagree with this statement.
10. You notice your neighbour replacing her exterior house lights with lower watt bulbs. Would you describe this as "conservation" or "sustainability"?
11. Cars today include electronic systems that control much of their operation. Identify one benefit and one drawback to the use of these electronic systems.

Focus On SCIENCE AND TECHNOLOGY

Technological problems can often be resolved with more than one solution. The different solutions may involve a variety of designs, processes, and materials. Think about what you learned in this section.

1. Give one example that you encountered of a problem that had more than one solution.
2. Was one solution better than the others? Why or why not?
3. If you did Activity D-12 Problem Solving: Harness the Wind, how did you know when you had a solution that would work?



Unit Summary: Electrical Principles and Technologies

Key Concepts / Section Summaries

1.0

Key Concepts:

- electric charge and current
- circuits
- electrical energy storage
- energy transmission
- measures and units of electrical energy

1.0 Electrical energy can be transferred and stored.

- There are two types of electricity: static and current. Static is electrically charged particles at rest. Current is flowing electrically charged particles.
- Voltage is a measure of how much electrical energy each charged particle carries. Current is the rate at which charged particles flow.
- Electricity can be dangerous, so safety should always be a concern.
- Electricity can be produced through chemical reactions and stored in different types of cells. Cells can be combined to form batteries.

2.0

Key Concepts:

- electric current
- circuits
- energy transmission
- measures and units of electrical energy
- electrical resistance and Ohm's law

2.0 Technologies can be used to transfer and control electrical energy.

- Different substances provide various levels of resistance to electric current. Electricity flows more easily in conductors than in insulators.
- The amount of electrical resistance is measured in ohms. Voltage is measured in volts. Current is measured in amperes.
- Ohm's law states that the current flowing through a conductor is proportional to the voltage applied to it.
- Meters are used to measure electricity. Voltmeters measure voltage. Ammeters measure current. Ohmmeters measure resistance. Multimeters measure all three.
- Series circuits provide a single pathway for current. Parallel circuits provide multiple pathways for current.

3.0

Key Concepts:

- forms of energy
- energy transformation
- generation of electrical energy
- energy transmission
- measures and units of electrical energy

3.0 Devices and systems convert energy with varying efficiencies.

- Energy exists in different forms, such as chemical, thermal, mechanical, and electrical energy.
- Energy can be transformed from one form into another. For example, a thermocouple can change thermal energy into electrical energy.
- Electric motors transform electrical energy to mechanical energy.
- Power is the rate at which a device converts energy. It is calculated by multiplying current by voltage. Energy is calculated by multiplying power by time.
- Input energy and usable output energy can be compared to determine the efficiency of an energy-converting device.
- Reducing the amount of energy wasted by devices that convert energy increases their efficiency.

4.0

Key Concepts:

- energy transformation
- energy transmission
- generation of electrical energy
- energy storage
- renewable and nonrenewable energy

4.0 The use of electrical energy affects society and the environment.

- A variety of alternative energy sources can be used to generate electrical energy. These include fossil fuels, nuclear energy, geothermal energy, biomass, hydro-electricity, tides, wind power, and solar energy.
- Energy sources are either renewable or nonrenewable.
- Electrical generation can produce by-products and effects that harm the environment.
- Energy and nonrenewable resources can be conserved through choices that reduce consumption.
- Sustainability means using resources at a rate that can be maintained indefinitely.

Three Gorges Dam

The Issue

In 1994, the Chinese government began a massive project on the Yangtze River called the Three Gorges Dam. The project is designed to provide electricity to large areas of rural China, where many people live in poverty without electricity. It will also control flooding. The Yangtze often overflows and floods large areas of northern and central China. In the 20th century, such flooding killed over 300 000 people. When it is completed in 2009, this dam will be one of the largest in the world.

- When complete, the dam will be 2.3 km across and 185 m tall. It will create a lake about 600 km long and 200 m deep.
- The dam will require 27 million cubic metres of concrete. That's enough concrete to cover 4000 football fields to a depth of one metre!
- The dam will produce over 18 GW (gigawatts) of power.

Many people in other countries and in China do not think the dam should be built. The chart below gives two different viewpoints about the project.

Go Further

Now it's your turn. Use the following resources to help you learn more.

- Look on the Web: Use the Internet to find out about the Three Gorges Dam. Begin your search at www.pearsoned.ca/scienceinaction.
- Ask the Experts: Many engineers and archeologists are available through question-and-answer sites on the Internet. A local energy council or government agency may also be able to give you information.
- Look It Up in Newspapers and Magazines: Check for articles about this issue in newspapers and magazines.

Analyze and Address the Issue

Use the information you have gathered to analyze the costs and benefits of the Three Gorges Dam project. Write a brief report stating your conclusion about whether the project should be completed. Support your conclusion with your research data.

Should China Complete the Three Gorges Dam?

Yes	No
The dam may be able to stop devastating flooding. The dam's control mechanisms may be able to save lives by managing water levels.	**The dam presents an even worse flooding danger if it fails**. Millions of people live downstream of the dam. A failure of the dam would be catastrophic.
The dam would produce much needed electricity. The poor of rural China do not even have refrigerators. Electricity would provide the possibility of modern conveniences.	**The dam requires almost 2 million people to be uprooted and relocated.** The reservoir will flood thousands of farms and villages.
Electricity would provide the means for modernization. Rural China has few of the advantages of even the smallest Western communities. With electrical power, rural Chinese can begin to modernize their economy.	**The dam's reservoir will submerge many priceless artifacts and natural treasures.** Over a thousand archeological sites will be ruined.

PROJECT

BUILDING AN ELECTRICAL DEVICE

Getting Started

Designing an electrical device offers many opportunities to discover answers for yourself. In this activity, you will plan how to build an electrical device that performs a particular function. Then you will build and modify a prototype. Using your choice of materials and what you have learned about electrical circuits, you will design a device or model of your own choice.

Your Goal

Demonstrate your understanding of electrical circuitry and energy conversions by using your imagination to pick a device or model to build. It can be any device that *uses electricity to perform a task.* Your goal will be to build the device that can successfully performs the task(s) of your choice. For example, consider building one of the following:

- a reversible escalator with an emergency switch
- a model electrically wired home, with special features such a pressure-sensitive welcome mat light
- a model animal kennel with doors that open electrically
- a rescue truck that moves and has a ladder that can be raised or lowered
- a switch-operated animal feeder that allows you to release food remotely

What You Need to Know

TOOLBOX

This project involves designing electrical circuits. Review what you have learned about electrical circuits and converting electrical energy into different forms. Recall how to supply current to a circuit and then control the current so that the circuit performs the task you desire. For your design to work, you will have to combine these concepts successfully. Before you begin, you may want to review Toolbox 3 to help you with problem solving as you develop your device. You may also want to consult Toolbox 13 to review the electrical symbols you need to use in your circuit diagrams.

Steps to Success

1 With your group, brainstorm ideas for solutions to the problem. Sketch ideas as you come up with them.

2 Decide what equipment you will need. Are there materials you can collect from home? Ask your teacher for help with any of the materials that you cannot collect yourself.

3 Carefully consider safety before you begin to construct your prototype. Show your teacher your final plan for approval, and then begin building your device.

4 When you have built your device, test to see if it meets your goals. After your test, you may need to make some changes and repeat the tests.

5 Look at your classmates' devices. Make a quick sketch of one of their designs and of a modification to improve it. Discuss this modification with your classmates.

How Did It Go?

6 Now that you have planned and constructed your device, write an evaluation of your approach to solving this problem. Did it work well? What would you do differently and why?

Unit Review: Electrical Principles and Technologies

Unit Vocabulary

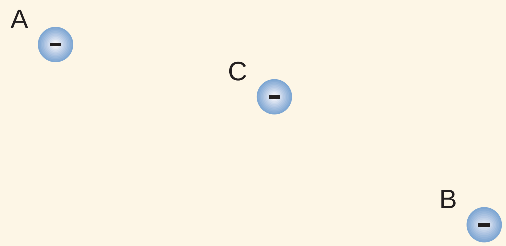
1. Create a concept map that shows how each of the following terms are connected. Use the word *electricity* as your starting word.

energy	resistance
batteries	series
motor	efficiency
current	cells
insulator	mechanical energy
power	voltage
electrolyte	conductor
generator	parallel

Key Concept Review

1.0

2. How can a Van de Graaff generator help in the study of electrical charge?
3. Describe an electric power grid. What is its purpose?
4. Consider two negative charges that are fixed in position (A and B below). What would happen if a movable negative charge were placed at point C? Explain.



5. What is a short circuit? Is it dangerous? Explain.
6. Explain how an electrical wet cell functions.

2.0

7. A friend replaces a cord on a kettle with a new one much thinner than the original. When the kettle is plugged in, the new cord gets much hotter than the old one did. Explain why.
8. Dimmer switches are convenient ways of controlling the amount of light in a room. Describe how a dimmer switch works.
9. Use Ohm's law to solve the following problems:
   a) What voltage is applied to a 5.0-Ω resistor if the current is 1.5 A?
   b) A voltage of 80 V is applied across a 20-Ω resistor. What is the current through the resistor?
   c) The current running through a starter motor in a car is 240 A. If this motor is connected to a 12-V battery, what is the resistance of the motor?
10. Use electrical symbols to draw a series circuit with a four-cell battery, a motor, and two bulbs. Draw a parallel circuit using the same components. Describe the difference in current flowing through the two circuits.

3.0

11. What do the terms "work" and "energy" mean?
12. What is the role of the commutator in an electric motor?
13. Would it make more sense for an electric company to charge by the joule or by the watt? Explain.

14. Solve the following power problems:
a) The current running through a coffee maker connected to a 120-V source is 8.0 A. What is the power rating of this device?
b) A 120-W motor draws 1.2 A of current. What is the voltage across the motor?
c) A 5000-W dryer is connected to a 240-V source. What is the current flowing through the dryer?

15. How much energy does a 100-W light bulb use in an hour?

16. A 500-W hot plate adds 250 kJ of energy to a container of water while heating for 10 min. How efficient is this heating process?

17. Use the example of a gasoline-powered car to explain the concepts of input energy, output energy, and efficiency.

18. Describe three methods for reducing the amount of energy wasted in the home.

4.0

19. Could a thermal generating plant be effective without a turbine? Explain.

20. What is meant by a "non-thermal" method of generating electricity? Describe an example of such a method.

21. Discuss the positive and negative aspects of generating electricity with coal, nuclear power, and wind power.

22. Describe the difference between renewable and nonrenewable energy sources. Give two examples of each.

23. If current world oil reserves will last longer than your lifetime, why should you bother to conserve energy?

24. Describe the advantages and disadvantages of transmitting information electronically.

Connect Your Understanding

25. Explain why a cow that touches an electric fence gets a mild shock, but a bird sitting on the same wire doesn't feel any electricity at all.

26. A classmate would like to connect multiple motors together in a circuit. But every time a motor is added, an undesirable side effect occurs—all of them spin a little slower. Discuss possible solutions and explain how they would correct the problem.

27. You receive a nasty shock from a kettle with a frayed cord, and your arm temporarily feels numb. Is this numb feeling caused by current or voltage? Explain.

Extend Your Understanding

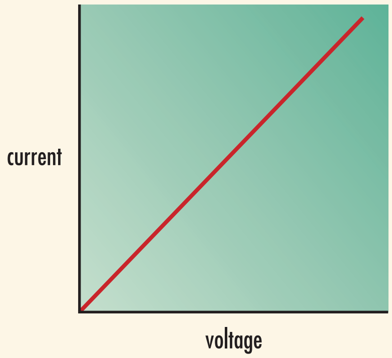
28. Does a decision to conserve a resource mean that the resource now becomes sustainable? Explain.

29. Does it make any sense to spend more money for a more efficient appliance? Explain.

30. Thinking that a loose electrical cable has been turned off, a construction worker tries to move it. The voltage contracts the worker's muscles, so they cannot let go of the wire. A wooden pole and a copper pipe are nearby. Could you use either of them to nudge the victim away from the live wire? Explain.

Practise Your Skills

31. This graph shows the relationship between voltage and current that emerged in tests for a particular resistor. Does this resistor work according to Ohm's law? Explain.



32. Construct a graph similar to the one above. Draw two lines that would represent the relationship between current and voltage for two resistors of different values. Write a short summary statement explaining the lines you have drawn.

Self Assessment

33. List two questions about elecctricity-related issues that you'd like to explore further.

34. How could you improve the results of your work in the problem solving and inquiry activities you did in this unit?

35. How could you improve your work in group situations?

Focus On Science and Technology

In this unit, you have investigated science and technology related to electrical principles and technologies. Consider the following questions.

36. Reread the three questions on page 273 about science and technology related to electrical principles and technologies. Use a creative way to show your understanding of one of these questions.

37. Describe an example of how an advance in science led to the development of a useful new technology.

38. Describe how the development of electrical technologies affects and is affected by the environment.