Electricity. It’s all around you. It’s invisible. It can be used for many purposes such as listening to music, finding your way down a dark path, or talking to a relative in another part of Canada. You will participate in an electric adventure as you learn about electricity.

Now you will find out:

- how electricity is transformed into sound, light, and motion
- how to design electrical devices to send coded messages to a friend
- how to identify uses of electricity in your school, home, and community
Get Started

Electricity is everywhere! It can be found in your house, your school, at the soccer field, or baseball diamond. Use the illustration on these two pages. Identify and list as many examples as you can of electricity being used.

Work On It

With your partner or group, share your list of examples. Group all the examples in categories that make sense to your group. Label each category. Share your group’s ideas with the class.

Communicate

1. After listening to the other groups, what categories would you use to classify your list now? Reclassify your list using these new categories. Don’t forget to include any additional observations you have made.

2. What is one example of electricity you would add to the picture? Draw what you think this would look like.
3. Use the words in your list. Make a cinquain poem. A cinquain poem has five lines. The first line is one word on the topic (a noun). The second line is two describing words (adjectives). The third line is three action words (verbs). The fourth line is a four-word phrase describing a feeling. The fifth line is another word for the topic.
The Shocking Background to Electricity

If you want to operate a portable radio or walkman, you need batteries. These batteries can be purchased at most stores. Sometimes they are rechargeable. This has not always been the case. Imagine yourself back in the past, before television, cars, and light bulbs. You are now 200 years back in time. Canada will not become a country for another 50 years. There were no fridges to keep the food cold like the fridges we use today. This is because there was no electricity. What do you think people used to keep their food cold? Draw what you think was used to keep food cold.

Luigi Galvani was an Italian scientist and a medical doctor. In 1786, while examining a dead frog, he noticed that a spark could make the frog’s leg move, when two different metals were touching the frog’s leg. He was curious as to why this happened. He wondered if he could repeat the observation under different conditions. Galvani guessed that the spark travelled from one metal, through the frog’s muscle, and then into the other metal. While this later turned out to be the correct guess, he didn’t know how this could happen. But he was determined to find out.

As the next lightning storm approached, Galvani used a brass hook to hold the frog’s muscle and attached this hook to an iron railing. He knew the storm would create a spark.

Review the drawing of your fridge with others in your class. Aren’t you glad that we have access to electrical devices like fridges, ovens, and computers? How did humans discover and harness electricity? Believe it or not, it all started with a frog’s leg, a brass hook, an iron railing, and a lightning storm.

If you finish your drawing before the others in your class, draw what you think a kitchen would have looked like 200 years ago.
The spark could then travel between the brass hook and iron railing to make the muscle move. As the rain came down and the lightning flashed around him, he observed and recorded the changes to the muscle. He noticed that the muscle moved! Using his observations, he proposed that the muscle moved because of electricity. While there was much excitement in his town and country about the discovery of electricity, it was only the beginning of the investigation for scientists all around the world.

**Electrical Muscles**

If a person has a leg or arm amputated, it is usually replaced with a device called a prosthetic, or artificial leg or arm. Today, scientists are investigating ways to make artificial legs or arms move. Just like Galvani’s experiments, they are using electricity to make an arm move up and down or a leg bend at the knee.

In 1796, after Galvani’s muscle experiment, another scientist from Italy, Alessandro Volta, wondered if he could make electricity rather than observe it. Instead of using a frog’s muscle, Volta used different liquids. He placed these liquids in bowls and then connected the bowls with pieces of metal.

Volta discovered that when he used saltwater in the bowl and connected the bowls with copper and zinc metal, he could produce a spark. This was very exciting because he designed a chemical cell which would soon become a battery!

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In 1967, then 17-year-old Richard Keefer of Ontario invented a battery that could run on garbage! The battery lasted longer than store bought batteries and cost about the same price.

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1. Imagine life 200 years ago, without electrical devices. Which of these electrical devices would you miss most?

2. Describe what a day in your life would be like, if you had no electricity.

3. Work with a small group. Read and discuss the following statement: “We are more dependent on electricity than people in the past.” Present your ideas to the class.

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As you learn about electricity, you will build an Electric Timeline. The Electric Timeline will be a visual representation of important inventors or inventions in electricity. Start your Timeline with Galvani’s discovery about electricity in 1786.
Characteristics
of Electricity

Get Started
You now know about the discovery of electricity and batteries by scientists over 200 years ago. It is time for you to explore the characteristics of electricity. Before you start, write down your thoughts about the following statements and make sure to include an explanation if you can.

- Can you make electricity with a fruit and six cents?
- Can electricity make objects move?
- Can electricity go through a toothpick, fork, or straw?

Work On It
Your teacher will set up three electrical exploration centres. At each centre, you will complete the procedure and answer the questions. When instructed by your teacher, move to the next centre.

Electrical Lemon Centre
Centre 1: Determine if foods can act like a battery and light a light-emitting diode.

Procedure

Materials for each group:
1 lemon
1 banana
1 orange
1 slice of bread
1 penny
1 nickel
2 wires with alligator clips (each wire about 30 cm long)
1 small type of light bulb called a light-emitting diode or LED

Always remember to clean up your centre so that someone else can use the equipment.
1. Do you think any of these foods can make the LED light up? Record your prediction.

2. Connect one of the wires to the LED by attaching the wire to one of the LED metal ends. Attach the other wire to the other metal end of the LED.

3. Insert the penny into one of the foods.

4. Insert the nickel into the same food, about 3 cm from the penny.

5. Connect one of the wire ends to the penny and the other wire end to the nickel.

6. Observe the LED. Record your observations.

7. Repeat steps 3 to 6 for each food.

8. Reread your prediction. Were you surprised by the results of this investigation? Describe your thoughts after you tested the first food.


10. Where do you think the battery in foods receives its energy from to light up the LED?

11. Identify and describe any energy transformations you think are occurring, when the food lights up the LED.

**Lights On–Lights Off Centre**

**Centre 2:** Determine which materials allow electricity to pass through them.

**Procedure**

To test which materials will allow electricity to pass through them, you will need to construct an electrical tester.

1. Connect one end of a wire to the end of the battery labelled +. Connect another end of a wire to the end of the battery labeled –. Use the wire connected to the + end of the battery, and connect it to one of the LED metal ends. Take a third wire and connect it to the other metal end of the LED. You should now have two wires.

**Materials for each group:**

- 1 metal spoon
- 1 piece of wood
- 1 quarter
- 1 pen
- 6V battery
- 1 glass of water
- 1 glass of saltwater
- 1 LED
- 3 wires with alligator clips (each wire about 30 cm long)

2. Repeat steps 4 to 8 for one of the foods, but increase and decrease the distance between the penny and the nickel. Does changing the distance have an effect on the LED?
that each have an end that is not connected to anything. Your electrical tester should look like the diagram.

3. Make a list of the remaining materials at your centre. These are the materials you will be testing. Add two columns beside the list of materials. Label one column Prediction and one column Observation.

<table>
<thead>
<tr>
<th>Material</th>
<th>Prediction</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>metal spoon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>piece of wood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>quarter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>glass of water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>glass of saltwater</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Select one of the remaining materials. Connect your electrical tester to it by attaching one wire end to one end of the material, and the other wire end to the other end of the material. The distance between the two wires should be about 5 cm.

5. Observe and record your observations.

6. Disconnect the wires from the material.

7. Repeat steps 4 to 6 until all objects have been tested.

If Time Allows

Pick two additional objects in the room to test. Try to select one object you think will make the LED come on, and another object that will keep the LED off. Record your predictions and observations in the table.

If Time Allows

Repeat steps 4 to 6 for one of the objects, but increase and decrease the distance between the two wires. Does distance between the wires affect the brightness of the LED?

8. Any material that allows electricity to pass through it is called a **conductor**. Any material that does not allow electricity to pass through it is called an **insulator**. What material would you use to make a light bulb go on – a conductor or an insulator?

9. Based on your investigation, which materials would make good conductors?

10. Describe a situation where an insulator is used in an electrical device.
Electricity—Transforming Energy Centre

**Centre 3:** Identify and describe how each toy transforms electrical energy into other forms of energy.

**Procedure**

**Materials for each group:**
- a toy monkey that makes noise (or a toy that talks)
- a toy robot (or a toy with lights)
- a toy police car (or a toy that moves)

1. Turn on each of the toys and observe how each works.
2. Turn off the toys.
3. List and describe the characteristics which all three toys have in common.
4. List and describe the characteristics that make each toy different from the others.
5. Which characteristics can you observe only when the toys are operating?
6. Energy transformations occur when electrical energy is converted to heat energy, mechanical energy, and chemical energy. Describe examples of energy transformations you observed in the toys.

**Communicate**

1. Use the information from the three activities. Create a mind map that represents your understanding of the characteristics of electricity. To help you, start with a central picture representing a situation that uses electricity.
   
   2. Complete the sentence: “I know electricity can move from one place to another because...”
Where Does Electricity Come From?

Get Started

Before you make a decision, it is important to have all the information that will help you make that decision. Would you buy a game for your friend without knowing if she would like it? Would you go on a trip without making sure you knew how to get there and where you would stay?

You can find some of this information by asking someone. Other information needs to be researched. When you do your research, it is important to keep all the information organized. One method of organizing information is in a + and – chart. This type of chart allows you to identify the positive and negative characteristics of the particular subject you are studying. Look at the chart. This is an example of how one student listed the information using the + and – to help him decide if he should buy a bicycle.

**SHOULD I BUY A BIKE?**

<table>
<thead>
<tr>
<th>+</th>
<th>–</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Would like to buy a bike</td>
<td>• still have to save more money for bike</td>
</tr>
<tr>
<td>• could ride it to school</td>
<td>• need a place to store bike</td>
</tr>
<tr>
<td>• could ride it to music lessons</td>
<td>• need to buy a bike helmet and a lock</td>
</tr>
<tr>
<td>• could ride it to baseball practice</td>
<td>• not all my friends have bikes</td>
</tr>
</tbody>
</table>

Work On It

A + and – chart can also be used for collecting science information. You are going to read about five different ways to generate electricity. Each way has positive and negative effects on your community and the environment. Work with a partner. Create a + and – chart for the different ways to generate electricity.

There are two major categories for classifying types of energy resources — **renewable** and **non-renewable**. A renewable energy resource can be used over and over. It is never used up. Hydroelectricity, wind, and solar energy are examples of renewable energy resources. A non-renewable energy resource can only be used once. Coal is an example of a non-renewable energy source.
Renewable Energy Resources

Hydroelectricity

Hydroelectric dams create electricity by having a flow of water turn a **generator**. A generator is a device that can create electricity, if it can be made to spin. The water needed to spin the generator usually comes from a river, that has been blocked by a dam. The water that is blocked by the dam is called a **reservoir**. This reservoir can be used for both recreational purposes and farm irrigation. It ensures that there will always be water available to turn the generators and make electricity. Electrical generators operate without creating air pollution and are reasonably cheap to operate.

Unfortunately, the large dams needed for the production of electricity are expensive to build. For each dam there is only a limited number of spots where they can be built. Once the dam is built, the reservoirs can destroy local ecosystems and flood agricultural land. One characteristic of hydroelectric dams is the transmission lines needed to carry the electricity from the dams to cities in Canada. These transmission lines are usually long and expensive to build.

Solar Energy

**Solar energy** uses the energy from the sun and transforms it into other forms of energy. For example, the sun could be used to heat water for showers, washing dishes, and other household needs. This is called **passive solar heating**. **Active solar heating** occurs when solar energy is used in conjunction with other electrical devices.

Solar energy is available everywhere the sun shines. It is simple to use. Devices such as solar panels can be added to houses quite easily. There is no pollution created when solar energy is used to generate electricity.

However, using solar energy to generate electricity does have several problems. The sun only shines for part of the day, and some
days may be cloudy. A solar cell used to generate electricity is quite expensive. Over time it is expected that costs will get cheaper. Generating solar energy takes up a lot of space. Most solar-generated electricity is produced on a small scale because it would take a large area of land to produce a vast amount of electricity.

**Wind**

Collecting energy from the wind requires a windmill, turbine, or blade to catch and turn in the wind. There are many different types of devices that can be used. Four of the more common types are pictured here. Each kind has been used in Canada, but the multiblade and two- or three-blade high speed rotors are the most common.

Wind is free, renewable, and pollution free. Windmills can be set up faster than dams or coal power plants. Unfortunately wind speed is variable, turbines break down, birds can be killed flying into them, and the electricity is expensive to generate.

From left to right, clockwise: Multiblade, three-blade high speed rotor, and two vertical axis wind generators.
Non-Renewable Energy Resources

Nuclear Energy

About 50 years ago a process to control the breakdown of the smallest units of matter was discovered. During the breakdown of matter, energy was given off. This energy can be harnessed and used to produce electricity. The most common material used for this process is uranium. The production of electricity occurs in a nuclear power plant. Canadian scientists and engineers have developed one type of nuclear power plant called the Canada Deuterium-Uranium reactor, or CANDU reactor.

The CANDU reactor converts the energy given off from the breakdown of matter to heat water into steam. The steam is then used to spin generators to create electricity.

The cost of uranium fuel is relatively cheap. Uranium can be found in many parts of the world. Nuclear power plants do not produce air pollution that cause environmental concerns like acid rain. For many countries, the use of nuclear energy is an option if no other forms of energy production are available.

The use of nuclear energy requires several considerations. There are only about another 100 years of uranium supply left for use. A nuclear power plant is expensive to build. A nuclear power plant functions for 30 to 50 years before it must be dismantled. The waste from a nuclear power plant is highly radioactive and must be carefully handled and stored for a long period of time. While the chance of a nuclear accident is low, any major incident would have an impact on the whole country.
Coal

Coal is mined in all the provinces of Canada, except Manitoba and Quebec. Once mined from the ground, it is commonly burned to make electricity and steel. In fact, almost half of the world's electricity comes from burning coal. To generate electricity, coal is burned to heat water into steam. The steam is then used to spin generators to create electricity. This is similar to the generators in dams, except that in dams water is used instead of steam.

Using coal for making electricity is relatively cheap, and the world has a large quantity of coal available. An added benefit of using coal is that other products can be made from it. These products include fertilizers, paints, and plastics.

However, using coal has certain disadvantages too. Mining coal can be dangerous and disruptive to the environment. Burning coal can create air and water pollution. As coal is non-renewable, it will eventually be used up, or be too expensive to mine.

Communicate

1. Compare your + and – chart with another group in your class. Identify areas where your charts are the same and where they are different.
2. Discuss the differences in the charts.
3. Write a paragraph that describes the positive and negative effects of the five energy sources.
4. A new electrical generation facility is going to be installed in your area. Write a paragraph explaining what energy source to use. Use the information in this activity. Research any additional information in the library or on the Internet. Your paragraph should include:
   • the reason you chose the energy source you did
   • how expensive the method is
   • what effect it has on the environment and the natural resources

Assume your area has equal access to all energy resources.

Build On What You Know

Add any important energy discoveries to your Electric Timeline. Can you add another important discovery or inventor that isn’t in this activity?
Light bulbs, wires, batteries, and switches. These are all important in making electrical circuits. But, how do you get them to work together? There is only one way to find out. Try it!

Your task is to solve each electro problem. Use the materials from the list. When you think you have solved the problem, draw your solution. Have your teacher check it.

**Material for each group:**
- 2 light bulbs and light bulb holders
- 4 wires with alligator clips (each wire about 30 cm long)
- 6V battery
- 1 switch

**Electro Problem 1**
How can you make a light bulb go on?

**Electro Problem 2**
Can you make a light bulb go on and off using the switch?

**Electro Problem 3**
Can you have two light bulbs on at the same time?

**Electro Problem 4**
Can you make two lights go on, but when you unplug one of the lights, the other light stays on? Hint: You may need to share your materials with another group.
Communicate

Write

1. What materials did you need to make a light bulb light?

2. Which of the diagrams below will make a light bulb light?

3. In your own words, explain how you think a light bulb goes on when it is connected to a battery.

![Diagram of light bulb connections]

Build
On What You Know

The first light bulb was invented by Thomas Edison in 1879. During his lifetime, Edison developed 1093 inventions. Two of his inventions are the motion picture camera and the phonograph. Add Edison to your Electric Timeline.
Key Features of Electrical Circuits

Get Started

You are now an official investigator of electrical circuits. As with any good investigator, it is important to make sure that everyone you work with uses the same terms and language. Working with electrical circuits is no different. You may have noticed that you and your partner sometimes use different words for the same thing. This could get very confusing – fast!

To help reduce confusion, there are terms and symbols connected with each piece of electrical equipment.

Work On It

As you read this lesson, you will keep a list of terms and symbols that are new to you or your partner on an electrical place mat. The electrical place mat should be a large piece of paper between you and your partner. As you see a term or symbol that is new to you, write it down anywhere on the paper.

Key Features of an Electrical System

Conducting Material

Any material that can carry electricity is conducting material. Usually the common term for this material is called a wire. A wire is drawn in either a straight line or at a right angle if the wire changes direction.

Electrical Device

An electrical device is anything that requires electricity to operate. A radio, television, computer, walkman, light bulb or LED are all examples of electrical devices.

For your activity, light bulbs and LEDs will almost always be used. The symbol for a light bulb is:

The symbol for an LED is:
Energy Source

All circuits need some type of energy source. The energy source for the circuits you will use is a battery or electric cell. It is called a primary cell if it cannot be recharged, and a secondary cell if it can be recharged.

The symbol for a cell or battery is:

Switch or Control

There are many different types of switches available. Each switch can create a different way to control an electrical device. For example, think of a light switch. This kind of switch is called a toggle switch. Switches that can perform a similar function are called a slide switch and a popper switch. Can you think of an electrical device where you have seen these switches working?

Switches can also be used to control electrical devices by detecting, pressure, heat, and light.

The reed switch works when two wires are pressed together to complete a circuit. This switch could be used under a doormat and be connected to the doorbell. When someone steps on the mat, the doorbell rings.

The tilt switch can be found in a thermostat. As the temperature goes down, the bi-metal strip bends and moves the switch to the right. The mercury rolls to the right and connects the two wires. The thermostat will turn the heater on. As the room heats up, the bi-metal strip moves the other way. The mercury rolls back to the other side and disconnects the wires. The heater turns off.

The photoelectric cell detects light and produces electricity. This type of cell is also used in solar energy. When there is light, the circuit is on; when it is dark, the circuit is off.
For your activity, the symbol for a switch is:

![Open Switch](image1)

![Closed Switch](image2)

Use these symbols to draw your circuits. Anyone who has studied electricity will be able to read them. Make sure that your work is neat and clearly labelled.

This is an example of a simple circuit.

![Simple Circuit](image3)

This is the simple circuit drawn with symbols.

1. Work in groups of four. Compare your electric place mats. Circle the words that no one in your group can explain or define. Post those words on the board or chart. Discuss the definitions as a class.

2. Use your electric place mat and the words and definitions discussed in class. Make a concept map of all the terms.

3. Draw the following circuits using the correct symbols.
   a. One battery connected to two light bulbs.
   b. One battery and one LED that can be turned off and on with a switch.
   c. One battery and two light bulbs with a switch that can turn off both lights at the same time.
   d. One battery and two LEDs with two switches so that one light can be off and one light can be on.

4. Design on paper a security flashlight that has a switch that works by movement or pressure.

If Time Allows

Try and build the device you designed in question 4.
Different Needs, Different Circuits

Get Started

Now that you know about the key features of an electrical circuit, you can investigate different types of circuits. In the Light Up the Class activity, you started to build electrical circuits to solve a particular problem. In the previous activity, you identified the key features of an electrical circuit. Now you will use your understanding of electrical circuits to build two types of circuits. They are a **series circuit** and a **parallel circuit**. All circuits can be classified as one of these two types.

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**Safety Caution**

Make sure your hands are dry when touching electrical appliances and switches.

When wiring a parallel circuit, make sure it is disconnected from the battery to prevent shock.

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**Series Circuit**

**Procedure**

1. Connect one end of the wire to one end of the battery.
2. Connect the other end of the wire to the light bulb holder.
3. Using another wire, attach one end to the other side of the light bulb holder.
4. Attach the other end of the wire to the battery. If the light bulb goes on, you have a series circuit!

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**Materials for each pair:**

- 2 light bulbs and bulb holders
- 6 wires with alligator clips (each wire about 30 cm long)
- 6V battery
Circuit Check

A series circuit can be identified by having one loop. If you can place your finger on any part of the circuit and trace a path back to the start, you have a series circuit.

5. Disconnect one of the wires from the battery. Insert another light bulb in the series circuit.

6. Use the free end of the wire to attach to the light bulb holder.

7. Using another wire, attach one end to the other side of the light bulb holder and the other end to the battery. The diagram shows a completed circuit.

8. Unhook one of the light bulbs. Describe what happens.

Parallel Circuit

Procedure

1. Connect one end of the wire to one end of the battery.

2. At the free end of the wire, connect two other ends of wires. Check the diagram to make sure you have attached the wires correctly.

3. Connect a light bulb to one of the free ends. Use a second light bulb and connect it to the other free end.

4. Repeat steps 1 and 2 with the other end of the battery. You should now have four wires to be connected. Two have light bulbs at the end, and two have nothing. Can you describe what the circuit looks like? What type of food does it look like?
Circuit Check

A parallel circuit can be recognized by having more than one loop. If you can place your finger on any part of the circuit and trace a path, there will be a point where you have to choose which wire to follow. The diagram shows a completed circuit.

5. Connect the two free ends of the wires to the two light bulbs.

The dots in the above parallel circuit represent a connection between two or more wires.

6. Unhook one of the light bulbs. Does the other light bulb stay on? Record your observations.

Communicate

1. Give examples of similarities between a series and a parallel circuit. Give examples of differences between a series and a parallel circuit.

2. Why do you think the two light bulbs go out when one light bulb was unhooked in the series circuit?

3. Why do you think one light bulb stayed on when the other light bulb was unhooked in the parallel circuit?

4. Can you describe a situation where a series circuit could be used to operate an electrical device?

5. Can you describe a situation where a parallel circuit could be used to operate an electrical device?
Fixing Electrical Problems

Get Started

There are so many uses for electricity. But what happens when something breaks down? Maybe your television doesn't have sound when it is turned on or your hair dryer doesn't blow any hot air. What do you do? Many people take their broken appliances to a repair shop or have a technician come to the home.

When an electrical appliance is sent for repairs, the technician has to determine what is wrong. This process is called troubleshooting. Troubleshooting requires a person to ask a series of yes or no questions to determine the problem. Once the problem is known, it can be fixed. You are going to have an opportunity to develop your troubleshooting skills, and then a chance to try and solve an electrical problem.

Work On It

Before you begin troubleshooting the electrical problems, here is a guide to help you. Ask yourself each question and if the answer is yes, go on to the next one. If the answer is no, you have found one of the problems and will need to fix it.

<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Are the wires to the battery connected?</td>
<td>Check connections to battery. Reconnect if necessary.</td>
</tr>
<tr>
<td>2. If there is a switch, is it on?</td>
<td>Check to see if switch is on or stuck. Turn switch on, off, and on.</td>
</tr>
<tr>
<td>3. Are all the connections in the circuit attached properly?</td>
<td>Check all connections in the circuit. Reconnect if necessary. Check to see if anything is blocking part of the circuit.</td>
</tr>
<tr>
<td>4. If the circuit is a series circuit, is there only one complete loop?</td>
<td>Trace a path from one battery end, through the circuit and back to the other end of the battery. If one full loop not possible, rebuild circuit.</td>
</tr>
<tr>
<td>5. If the circuit is a parallel circuit, do any of the wires start and end at the same place?</td>
<td>Ensure none of wires start and end at the same place. Rebuild circuit if some wires are not properly attached.</td>
</tr>
<tr>
<td>6. Does the electrical device (like a light bulb) work?</td>
<td>Remove electrical device and replace with an electrical device you know works. If second electrical device doesn’t work, the problem is not the electrical device. Recheck your answers from steps 1 to 5.</td>
</tr>
</tbody>
</table>
Use the troubleshooting guide. Determine what is wrong with these six circuits. Remember to write down your solution to each problem.

**Problem 1**
Why won't this flashlight turn on?

**Problem 2**
Why won't the light bulbs light in the circuit?

**Problem 3**
Why won't the doorbell ring?

**Problem 4**
Why won't the bulbs light up?

**Problem 5**
Why won't one speaker play music?

**Problem 6**
Why won't one of the lights go on?
You have practised developing your troubleshooting skills. Now, solve the following problem. It was sent to a company that makes night lights. Send a response to Mr. Ohm with suggestions for fixing his broken lamp.

To: Bright Nite Light Corp.
From: Mr. Ohm
Re: Broken “Bright Light” night lamp

I would like to ask for your assistance in fixing my broken “Bright Light” night lamp. My daughter really likes her night lamp, but I am unable to fix it. I have taken the lamp apart and drawn what it looks like. I would appreciate any suggestions you could make to help me fix the lamp. Thank you for your help.

Sincerely,

Mr. Ohm

Mr. Ohm

The first illuminated glass sign was invented by John B. Studley of Nova Scotia in 1858. The sign used gas burners behind the glass sign rather than electrical light bulbs. Add Studley to the Electric Timeline.
Get Started

In previous activities, you have observed batteries turning chemical energy to electrical energy, which was transformed into sound, light, and motion energy. You have also observed that materials like salt water and metals can conduct electricity. You can also provide an example of electricity moving. For example, when you used your electrical tester and the metal spoon, electricity flowed from the battery, through the wires and the spoon to light the LED, and then back to the battery. In some situations, electricity does not move. This is called static electricity. Can you think of any examples of static electricity? Share your examples with a partner. Make a list with two columns. In the first column list the examples which you both agree are static electricity. In the second column list the examples which you and your partner are not sure are static electricity.

Work On It

The following advertisement about Magical Balloons was found on the Internet. Your task is to determine if your class should purchase a Magical Balloon. You will need to collect evidence to support your decision. Try to prove or disprove the claims in the advertisement by reproducing the “magical qualities” of the balloon.

Materials for each pair:
- 1 balloon
- 10 small pieces of paper
- 1 pencil
The Magical Balloon is an example of static electricity. Static electricity stays in one place. In this case, it stays on the balloon. Your investigation showed that static electricity can cause objects to move or stick to one another.

1. Determine which of the eight statements given below are characteristics of static electricity, and which are characteristics of current electricity:
   - You rub your feet on the carpet, touch something made of metal and get a shock.
   - You forget to use fabric softener when you wash your clothes, and they stick together when you take them out of the dryer.
   - You turn on the television.
   - On a cold evening, your jacket crackles when you take it off.
   - A flashlight is turned on.
   - Dust gathers under your bed.
   - The school bell rings.
   - You play a computer game.

2. Describe a situation in your life where both static and current electricity could be observed at the same time. Start your description with the following: “As I walked into my house …”

3. Review the list you and your partner made at the start of this activity. Look at the examples in both columns. Are there any changes or additions you would make to the list? If so, which ones would you change or add?
Learning About Magnets

Get Started

Have you ever played with magnets? Maybe you have seen one in a toy or a game or at school. They come in different shapes, sizes, and colours. They can pick up things, hold on to things, and move objects away. Sometimes magnets stick together or move away from each other.

Magnetism is the force around a magnet. It is strongest at a magnet’s poles. The poles are labelled N and S. N is for the North Pole of the magnet, and S is for the South Pole of the magnet. What would happen if you put the N of one magnet near the N of another magnet? What other way could you place two magnets so they would push away from each other? Which way could you place two magnets so they would stick together?

Work On It

Magnets can exert a force on an object and make it move without touching it. Some people may have called this magic a long time ago. But you can observe this effect by using a bar magnet and some iron filings. Place a piece of paper on your desk. Sprinkle some iron filings on the paper. Stick the magnet underneath the desk. Move the magnet around. Can you see the iron filings move? This is an example of magnetic force acting on the iron filings without actually touching the iron filings.

Let’s look at another example of magnetic force acting on an object at a distance.
Material for each student:
6V battery
1 wire (about 30 cm long)
1 compass
1 bar magnet

Procedure

1. Place the compass in the centre of your desk. Note the direction the compass needle is pointing.

2. Bring the magnet close to the compass needle, but do not touch the compass. Move the magnet around the compass. Describe what happens. Include words like attract, move, and point in your description.

3. Use the other end of your magnet. Repeat step 2.

4. Position the magnet so that it no longer affects the compass needle.

5. Now place the wire over the compass. Make sure it is positioned on top of the compass needle. See the photograph. Place a piece of tape on each side of the wire to hold it in place.

6. Connect one end of the wire to one end of the battery. Connect the other end of the wire to the other end of the battery. Quickly observe what happens to the compass needle.

7. Unhook one end of the wire from the battery. Observe what happens to the compass needle.

8. Repeat steps 6 and 7 to confirm your observations. Describe what you observed. Your description should start with: “When electricity flowed through the wire, I observed …”

Communicate

1. Describe what was similar between using the magnet and the compass, and the wire with electricity running through it and the compass.

2. In your own words, can you make a rule that would describe this situation?

3. Brainstorm with a partner possible uses of your electricity-magnet discovery.

Build On What You Know

In 1820, Danish teacher Hans Christian Oersted was the first person to discover that an electric current could cause a compass needle to move. Add Oersted to your Electric Timeline.
Did you know there are different kinds of magnets? Some magnets are permanent. These magnets stay magnetized for long periods of time. Other magnets are considered temporary. They can turn their magnetism on and off. For example, a motor, a fire alarm bell, and a telephone all require temporary magnets called electromagnets.

In the last activity, you learned that a compass needle moved when electricity moved through the wire. The electricity acted like a temporary magnet. As soon as the electricity was off, the compass returned to its normal position.

You are going to build an electromagnet. By the end of the activity, you should be able to describe its characteristics. Before you start, discuss with your partner how to get a paper clip and an iron nail to stick together.

**Materials for each pair:**
- 6V battery
- 3 wires with bare ends (about 30 cm, 45 cm, and 60 cm each)
- 1 iron nail
- 1 pencil
- 1 plastic film canister
- 40 paper clips

**Safety Caution**
Be careful! The nail will get hot very quickly. Do not touch the wire to the battery for a long time.
**Procedure**

1. Take the 30 cm wire and wrap it around the nail ten times. Attach the ends of the wire to the battery. Touch the nail and coil of wire to the pile of paper clips. Record your first response after you see the nail touch the paper clips.

2. Unhook one of the wires from the battery. Record your observations.

3. Discuss your observations with your partner. Why do you think the paper clips are attached to the nail?

4. What do you think will happen if the number of coils around the nail is decreased or increased? Make a table like the one seen here. Predict how many paper clips will be picked up with each number of coils. Test your prediction.

<table>
<thead>
<tr>
<th>Number of coils</th>
<th>Predicted Number of Paper Clips picked up</th>
<th>Actual Number of Paper Clips picked up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Instead of changing the number of coils in the wire, use the pencil to wrap the wire around. Before you start, predict which material will work better – the pencil or the plastic film canister?

6. Wrap 20 coils around the pencil. Attach the wires to the battery. Dip the pencil and coils into the pile of paper clips. Record how many paper clips were picked up. Unhook one wire from the battery.

7. Repeat step 6 with the plastic film canister.

**Communicate**

1. Draw a bar graph to show how many paper clips were picked up with a particular number of coils. What number of coils picked up the most paper clips?

2. Which material picked up the most paper clips? Which picked up the least?

3. Describe a situation where you think an electromagnet would make a job easier.

**Build**

**On What You Know**

One of the most common uses of an electromagnet is in a motor or generator. In a generator an electromagnet is spun around to produce electricity. In a previous activity, you read about generators. Can you remember what they were used for? The first generator was developed by Michael Faraday of England in 1831. A motor can use electricity to perform a function or activity. Can you find out when and where the first motor was invented? Add these dates to your Electric Timeline.
Talking on the phone, watching television, and sending an e-mail—what do these activities have in common? If you said they are all forms of communication, you would be right! These forms of communication also rely on electricity.

Before electricity, people had difficulty communicating across great distances. Sometimes it took weeks or months to get a message from Halifax to Vancouver. Now you can talk to almost anyone in the world instantly. How does this happen? Let's start with a Canadian discovery.

“The to be or not to be” are words spoken by Hamlet, the hero in the play Hamlet, written by William Shakespeare. They were also the first words spoken on a long distance telephone call from the Ontario inventor, Alexander Graham Bell. It was the summer of 1876. Bell used, among other things, a thin sheet of metal, a coil of wire wrapped around a magnet, and a battery to create a telephone. This device was able to convert sound into electricity, and back to sound. Now thousands of kilometres can separate where the sound was made and where it was heard. Canadians can now talk to each other instantly rather than wait weeks for a letter.

Did you know that the first owner of a telephone in Canada was Prime Minister Alexander MacKenzie? He used the phone to talk to the Governor-General in 1877.
When phones were first invented the person using the phone had to move the receiver between the ear and the mouth. Sometimes people got confused and talked when they should have listened or listened when they should have talked! In 1878, Cyril Duquet of Quebec designed a phone receiver to have both an ear and voice piece like the phones of today.

Canadians continued to be involved in inventing devices that used electricity to send signals over great distances. The first wireless voice message was sent by Quebec inventor Reginald A. Fessenden in 1900. His first message only travelled 2 km. In 1906, the world started to communicate by sending electronic signals through the atmosphere. Using a microphone, Fessenden’s voice was converted to a radio signal that could be sent and received at another location. The key to the operation? All of his devices required electricity.

One person talks on his or her phone, and the sound is converted into an electronic signal that is sent to the satellite. The satellite then sends the signal back down to the person you are speaking to.
DID YOU KNOW THAT CANADIANS DID THIS?

In 1924, Sir William Stephenson of Manitoba invented a method of sending pictures for newspapers over phone lines.

In 1927, Edward Samuels Rogers of Ontario made the first radio that could be plugged into a wall outlet.

In 1942, Donald L. Hings of British Columbia invented the portable transceiver, or Walkie-Talkie.

In 1972, Anik 1 was launched. It was the world’s first geostationary communications satellite. This satellite was the first one to allow ordinary people to communicate with each other by having their voices sent electronically through space.

In 1987, when Anita Luszszak was 15 years old, she developed a pulsating generator that used less energy to generate electrical power than the conventional power generators. The Albertan student won a gold medal at an international competition for inventors.

In 1998, electric cars have Canadian inventors very busy. Pierre Couture of Quebec is developing a car that has four electric motors on each wheel of the car. Ballard Power Systems Inc. of British Columbia is developing a fuel cell that will power the electric cars of the future.

From satellites to fiber optic communications, Canadians are leaders in the world of global communications. Using electricity, Canadians have found many ways to send signals throughout the world.

Communicate

1. Discuss with your classmates what you think will be the communication devices of the future.

2. Can you add any more Canadian inventions that use electricity, especially ones that convert electricity into a signal? Research this in the library and on the Internet.

Build

In 1901, the first radio transmission across the Atlantic Ocean occurred between the southwestern tip of England and St. John’s, Newfoundland. This experiment was designed by Guglielmo Marconi of Italy. Add Marconi and the other inventors you have just read about to your Electric Timeline.
Electricity – Use it Carefully

Electricity is something most of us assume will always be available. However, in many countries electricity is not as common. In Canada you can flip a switch and light a room, or turn on a television to watch a show. Many people in other countries do not have this same lifestyle. You are going to have an opportunity to compare the different energy lifestyles between a Canadian and a Mongolian student.

Before you make an energy comparison between two countries, you will need to have a method on which to base your comparison on. The amount of electricity used by an appliance is measured in a unit called kilowatt hours, or kWh. A kWh costs about five cents. A television that uses 1 kWh would cost five cents for every hour that it is turned on. A television turned on for three hours would cost fifteen cents.

<table>
<thead>
<tr>
<th>Electrical appliance</th>
<th>Energy usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerator</td>
<td>4 kWh</td>
</tr>
<tr>
<td>One load of laundry and dryer</td>
<td>5 kWh</td>
</tr>
<tr>
<td>Water heater</td>
<td>32 kWh</td>
</tr>
<tr>
<td>Stove</td>
<td>7 kWh</td>
</tr>
<tr>
<td>Electric kettle</td>
<td>1.5 kWh</td>
</tr>
<tr>
<td>Light bulb</td>
<td>1 kWh</td>
</tr>
<tr>
<td>Radio</td>
<td>0.25 kWh</td>
</tr>
<tr>
<td>Colour television</td>
<td>2 kWh</td>
</tr>
<tr>
<td>Black-and-white television</td>
<td>1 kWh</td>
</tr>
<tr>
<td>Hair dryer</td>
<td>0.2 kWh</td>
</tr>
<tr>
<td>Electric clock</td>
<td>0.25 kWh</td>
</tr>
<tr>
<td>Stereo</td>
<td>0.75 kWh</td>
</tr>
<tr>
<td>Dishwasher</td>
<td>1 kWh</td>
</tr>
<tr>
<td>Shower</td>
<td>1 kWh</td>
</tr>
</tbody>
</table>

The table shows approximately how many kilowatt hours an electrical appliance uses in a typical day.

1 kWh = 5 cents
2 kWh = 10 cents
3 kWh = 15 cents
Nine-year old Batsuury climbs out of bed and gets ready for school. She can see her mom and dad are already up and they have turned on the light bulb. Living in a one-room tent allows her to see her dad starting a fire in the stove. The stove also heats the tent. Her mom starts breakfast as she listens to the daily news report on their black-and-white television. Her mom asks her to go outside to the ice box and bring in the milk. As Batsuury goes outside the tent, or ger, she barely notices the sun. There is a haze in the air created by the coal-generating power plant. As she brings in the milk, her mom plugs in the electric kettle to make tea for the family. Batsuury lives with her mother, father, brother, sister, aunt, and cousin. While breakfast is being made, she puts on her school uniform. Another day has begun.

Halfway around the world, Jennifer is getting ready to go to a surprise birthday party. She and her dad have spent the afternoon baking a cake. Her brother, Rhys, wasn’t interested in helping, so he is playing video games on the colour television. Her mom is at work. As the cake is baking, Jennifer cleans the kitchen and by accident drops the leftover cake batter. The batter lands everywhere, including on her clothes. Luckily, she has time to take a shower and change her clothes before the party. While she blow-dries her hair, she listens to her favourite music on her clock radio. When she is ready to go, she grabs the cake from the refrigerator and thanks her dad for helping her. She also promises to clean out the dishwasher when she gets home.

1. Calculate how much energy in kilowatt hours each girl used.

2. Is there a difference in the amount of energy the girls used? Can you provide an explanation for this difference?

3. Do you think that we use too much or not enough electricity in Canada? Explain your answer.
Conserving Electricity

**Get Started**

The amount of electricity used by Canadians when compared to other countries is considered quite high. In 1996, Canada was the sixth largest user of electricity in the world. One of the ways to reduce our electricity use is to conserve it when possible. If everyone conserves a small amount of electricity, this can add up to huge savings. Join your partner or small group. Brainstorm all the different ways you can think of to save electricity at home and at school. When your list is complete, share it with the class.

**Work On It**

In your group, design an action plan that will identify five ways to conserve electricity. You may want to use the ideas from your list. For example, you may decide to turn out the light in your bedroom when you are not there. This may save 1 kWh per month. If everyone in Canada did this, we would save $1.5 million a month!

**Communicate**

1. Using your action plan, create a pledge form. You may wish to use the sample form provided here, or design your own. Keep this form as a reminder of the importance of conserving electricity.

   **STEPS TO AN ACTION PLAN**

<table>
<thead>
<tr>
<th>Identify a goal</th>
<th>Turn out the bedroom light</th>
<th>✔</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify what must be done to meet that goal</td>
<td>When leave bedroom, turn out light</td>
<td>✔</td>
</tr>
<tr>
<td>Determine if anything will prevent you or make it difficult for you to meet your goal</td>
<td>May not be last person in bedroom</td>
<td>✔</td>
</tr>
<tr>
<td>Describe how you will know when you meet that goal</td>
<td>Save family money on electrical energy bill</td>
<td>✔</td>
</tr>
</tbody>
</table>
   | State your completion date | End of school year | ☐

   **I,____________________ pledge to conserve electrical energy in these ways:**
   1. ______________________
   2. ______________________
   3. ______________________
   4. ______________________
   5. ______________________

   Student’s signature____________________
   Teachers signature____________________

2. Does your action plan cause people to gain or lose jobs? How? How does it affect the use of natural resources?
Get Started

Have you ever wondered how inventions are made? Sometimes people have an idea and other times they just try something and see how it works. Either way, inventors are willing to take risks and try things no one else has ever done. Sometimes the reward for your invention can last longer than a lifetime. An example of this is Elijah McCoy, the inventor of the automatic oil cup and the lawn sprinkler. He was born in Ontario in 1844 after his family fled to Canada to escape slavery in the United States. His inventions were so well received people referred to them as the “Real McCoy.” This term is still used today to indicate an object that is the actual object and not an imitation.

You have developed an Electric Timeline to illustrate important inventors or inventions in the area of electricity. Now it is time to add your name and invention to the Timeline!
You will design an electrical device that will send a signal to your friend at the other end of the room. Remember the following:

- You should be able to send the signal at any time.
- You should be able to repeat the signal.
- You should not disturb others around you, when you send the signal.

Procedure

1. Design your device on paper to see what it will look like. Label all parts. Include a short explanation of how your device will work.

2. Build and test your device. Troubleshoot if necessary.

3. Be prepared to answer questions about your device such as:
   - How does it work?
   - What type of energy transformations does it use?
   - Could your device be used in the future? How? Is your device environmentally friendly?

Communicate

1. Demonstrate your device to the class.

2. Suggest how you would improve your device next time.

3. Add your invention and your name to your Electric Timeline.
You have been given the task of designing an automatic electrical light system for a home workshop. The machines in the workshop are very noisy, so the door must be closed when the owner of the house is in the workshop. Since she often carries materials in and out of the workshop, it would be helpful to have an automatic light switch. The light must go on when the door closes and go off when the door opens. Also, there are two lights in the room that must work together. As a safety measure, the design should ensure that one light bulb will still work if the other goes out.

You may use any piece of equipment discussed in this unit to design your automatic light switch. The owner would like a neat, labelled diagram and a description explaining how the electrical system will operate. She will also need a list of materials to be purchased to build the electrical light system.

Now check your work.
- ✔ My work contains a diagram, a description, and a list of materials. Each is complete.
- ✔ My diagram uses appropriate symbols and is correctly labelled.
- ✔ In my design, the light goes off and on automatically when the door opens and closes.
- ✔ My design contains two lights that work independently.
Communicate

Now it’s time to think about how well you did. Use this chart to help you score your work. Four stars is the highest score for each.

<table>
<thead>
<tr>
<th>1 Star</th>
<th>2 Stars</th>
<th>3 Stars</th>
<th>4 Stars</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Star]</td>
<td>![Two Stars]</td>
<td>![Three Stars]</td>
<td>![Four Stars]</td>
</tr>
</tbody>
</table>

- How much do you know about electricity? Look at your diagram, your list of materials, and your description. Does your work show you know

  - A little about electricity
  - Some information about electricity
  - A lot of information about electricity
  - All about electricity?

- Look at the description of your diagram of the electrical circuit. Does your work show you have

  - A few of the skills to set up an electrical circuit
  - Some of the skills to set up an electrical circuit
  - Most of the skills to set up an electrical circuit
  - All of the skills to set up an electrical circuit?

- Now look again at your description. Will it be clear and precise to a reader?

  - Not very clear or precise
  - Somewhat clear and precise
  - Mostly clear and precise
  - Very clear and precise

- How well do you think you understand what the homeowner wanted?

  - Not much understanding
  - Some understanding
  - A good understanding
  - A complete understanding

Write a short note explaining how well you think you did.
What did you learn about electricity?

1. Describe some key discoveries in the history of electricity.

2. Identify five renewable and non-renewable energy resources. Write a description of how society uses one of each.

3. Draw a series circuit that has two LEDs, a battery, and a switch.

4. Draw a parallel circuit that has two light bulbs, a battery, and a switch to turn both lights off and on.

5. Describe a situation where a series circuit would be used and describe a situation where a parallel circuit would be used.

6. Explain how you would fix this circuit to make both light bulbs stay on all the time.

7. Describe three examples of static electricity.

8. An electromagnet has twenty coils around a wood stick and can pick up five paper clips. Describe how you could modify the electromagnet to pick up more paper clips.

9. What was the importance of Fessenden’s discovery to electronic communication?

10. What can you do to conserve electricity?
How Did You Do?

Answer the following questions to highlight what you learned in this unit.

1. List three things you didn’t know before the unit started.
2. Describe what you liked best in this unit.
3. Give yourself a pat on the back! What did you do well in this unit?
4. List three questions you still have about electricity.

Now you know a lot about electricity! Here are some things you’ve learned:

- Electricity was discovered by Luigi Galvani after examining a spark jump from a metal to a frog’s muscle and seeing the frog’s leg move.
- Electricity can come from a variety of renewable energy resources – hydro electricity, solar, and wind – and non-renewable energy resources – nuclear and coal.
- The decision to use one energy resource over another is complex.
- Electrical circuits require a battery, wires, and an electrical device to operate. Ideally they also have a switch to control how they operate.
- There are electrical symbols used to describe the setup of electrical circuits.
- The two most common types of circuits are series and parallel circuits. Each can be used for particular situations.
- If an electrical circuit is not working, you have to fix it using a process called troubleshooting.
- Static electricity is a type of electricity that does not move, but can be observed to have an effect on other objects.
- Electricity can create a magnetic field that can be used in electromagnets and motors.
- Canadian inventors had an important role in the development of electronic communications.
- Electricity usage varies throughout the world. We must all do our part to conserve electricity.
**active solar heating**  solar energy used in conjunction with other electrical devices to create heat

**battery**  a number of electric cells connected together that supply energy

**chemical energy**  the energy stored in the bonds between the smallest units of matter

**circuit**  an arrangement of electrical devices that allows electricity to flow through conductors

**coal**  a black mineral that can be burned to make electricity or used to make chemicals; a non-renewable resource

**conductor**  a material that allows electricity to pass through it

**electrical energy**  energy produced by a current flowing through a wire or other object

**electricity**  a form of energy that can flow through conductors

**electromagnets**  the temporary magnets made of an iron bar with coils of wire around it; they act as magnets when electricity flows through the wire coils

**fiber optic communications**  communication by means of light signals along thin glass fibers

**generator**  a device that creates electricity from the mechanical energy of the rotation of the centre of the generator

**insulator**  a material that does not allow electricity to pass through it

**kilowatt hours (kWh)**  a unit of measure of the amount of electricity

**light bulb**  the common name for an electric lamp that produces light by heating a thin wire thread to a very high temperature

**light-emitting diode (LED)**  a small type of light bulb

**magnetic force**  the force that acts between two magnets by pulling them together or pushing them away from each other

**magnetic poles**  the two ends of a magnet where the magnetic force is strongest

**magnetism**  the force around a magnet

**non-renewable**  an energy resource that can only be used once and cannot be replaced

**nuclear energy**  the energy produced by the breakdown of the smallest units of matter; the heat produced turns the water into steam, which drives the generators in nuclear power plants

**parallel circuit**  a path of electrical current that has more than one loop in the circuit

**passive solar heating**  the energy from the sun used to create heat

**popper switch**  a switch that can be pushed to turn electricity off and on

**primary cell**  a non-rechargeable device

**prosthesis**  an artificial body part

**radioactive**  a property of substances that give off energy when their smallest units of matter decay

**renewable**  an energy resource that can be used over and over or replaced

**reservoir**  the water that is blocked by a dam

**secondary cell**  a rechargeable device

**series circuit**  a path of electrical current that passes through each device in the circuit, one after another; a path that has one loop

**slide switch**  a switch used to turn electricity off and on by moving a slider back and forth

**solar energy**  the energy from the sun, either light or heat

**static electricity**  electricity that does not move

**toggle switch**  a switch used to turn electricity off and on using a lever

**troubleshooting**  the process of discovering and eliminating causes of trouble

**uranium**  a radioactive metal used in nuclear power plants

**Walkie-Talkie**  portable transceiver invented by Canadian Donald L. Hings in 1942

**wire**  a thin thread of metal that can carry electricity
Acknowledgments

The publisher wishes to thank the following sources for photographs, illustrations, articles, and other materials used in this book. Care has been taken to determine and locate ownership of copyright material used in this text. We will gladly receive information enabling us to rectify any errors or omissions in credits.

Photography

Illustration

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