CHAPTER

11 Harnessing Electrical Energy

Getting Started

1 If you use a 100-W bulb for 10 hours, you will use up 1 kilowatt hour (kW·h) of electrical energy. In 1999, in Ontario, that would cost you about $0.08. Look at the cost per kW·h for the single-use (disposable) cells in **Table 1** below.

How many times more expensive is the energy per kW·h for an AA disposable cell than the electrical energy we use in our homes? Find similar information about rechargeable cells on the Internet, and compare the costs per kW·h for rechargeable versus disposable cells.

Suggest reasons for the differences in cost per kW·h for the four sizes of disposable dry cells.

Table 1

Single Use	AAA Cell	AA Cell	C Cell	D Cell
cost per cell	$2.30	$1.89	$2.58	$2.58
cost per kW·h	$1300	$490	$260	$132

2 Sources of electrical energy range from the minute amounts produced by the magnetic tape in a portable tape player to that produced by nuclear generating stations. There are also some more unusual sources of electrical energy. This radio is powered by a large clockwork spring. You wind up the spring, and as the spring unwinds it produces sufficient energy to operate the radio for a short time. The electric bicycle is another example. The small, specially shaped batteries on these bicycles can be recharged each night.

Where or in what circumstances would these kinds of devices be most useful? List some of their advantages and disadvantages.

3 It's easy to list ways that automobiles improve our lives. Unfortunately, there are two major problems with the sources of energy used by automobiles: the fuels are nonrenewable, and their combustion causes air pollution.

Canadian engineers and scientists have developed a practical solution that can power vehicles with electricity generated from renewable fuel sources that give off only water as a byproduct. These remarkable devices are called fuel cells.

Two of the fuels that can power a fuel cell are ethanol and methanol. Why are these fuels classified as renewable sources of energy?

What other uses could an electricity-generating fuel cell system, small enough to fit into a subcompact car, have in our society?

Try This: Be Prepared

All of us have experienced power failures. Usually they last for a few minutes and are little more than annoying. But suppose the power remained off for hours, for days, or even for weeks. How would you cope?

1. Make a list of the effects that a loss of electricity would have if it lasted for several hours on (a) the coldest day in January, (b) the hottest day in July.
2. What differences would there be in your daily life during a prolonged power failure?

Reflecting

Think about the questions in 1, 2, 3. What ideas do you already have? What other questions do you have about electrical energy? Think about your answers and questions as you read the chapter.

11.1 Investigation

SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Energy Stored in Batteries

Have you ever accidentally left a flashlight switched on, or has your portable tape or CD player ever stopped because the battery is discharged? If you have ever experienced this annoying phenomenon, then you know that dry cells can only release electrical energy for a limited amount of time.

In this investigation you will study the factors related to the amount of energy released from a dry cell as it is discharged. You will need to use two circuits. Circuit 1 consists of a AAA rechargeable 1.5-V dry cell energy source that is connected to a single electrical load—a light bulb. Circuit 2 consists of an electrical energy source identical to that in Circuit 1, connected to two electrical loads identical to that used in Circuit 1. The electrical loads in Circuit 2 are connected in parallel.

Question

What factors affect the amount of energy released from a dry cell?

Hypothesis

If we observe the light bulb, measure the voltage drop across an electrical load, and the time taken to discharge the dry cell supplying the electrical energy, then we will be able to identify the factors affecting the amount of electrical energy the dry cell releases into the circuit.

Materials

- 2 fully charged rechargeable 1.5-V dry cells (AAA)
- 2 AAA dry cell holders
- 3 light bulbs (1.5-V)
- 3 light bulb holders
- 2 switches
- connecting leads
- voltmeter(s)
- stopwatch (timer)

Procedure

1 Draw the schematic circuit diagrams (5D) shown in **Figure 1**, and copy **Table 1** shown below to record your data.

2 Construct the circuits shown in **Figure 1**. Ask your teacher to inspect your circuits before continuing.

3 Close the switch in each circuit, and at the same time start the timer. Record the actual time when you closed the switch, and the readings on the voltmeters in each circuit. (Your teacher will instruct you on procedures to use if the discharge time of the dry cells is longer than one class.)

(a) Record your initial observations, check the meter readings at regular intervals, and write notes, below the table, on any other changes that may occur.

Figure 1

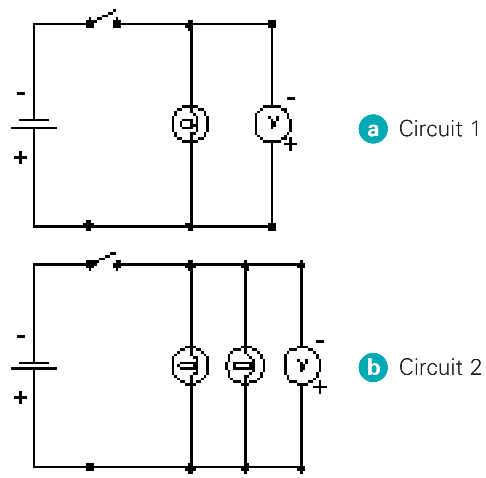


Table 1

	Voltage Drop (volts)	Ratio of Current in Circuit #2 compared to Circuit #1	Total Time Taken (hours)
Circuit 1	?	?	?
Circuit 2	?	?	?

4 When the dry cell in each circuit is discharged, record the time and stop the timer when the dry cells in both circuits are discharged. (The dry cell is to be considered as discharged when the bulb filament has just stopped glowing.)

(a) Record your observations.

Analysis and Communication

5 Analyze your observations by answering the following questions:

(a) How do you know that the same amount of energy was used in each circuit?

(b) What happened to the voltage drop across the light bulb as the dry cell was discharged? For what proportion of the time was the voltage drop reasonably constant in each of the two circuits?

(c) What can you infer about the ratio of the current in Circuit 2 compared to that in Circuit 1 (just after the two switches were closed)? Enter the value in the table. Explain your answer.

(d) How many times longer did it take for the electrical load in Circuit 2 to discharge the dry cell compared to Circuit 1? Suggest reasons for the difference.

(e) In what way does the electric current and the discharge time in Circuit 1 seem to be related to the same quantities in Circuit 2?

(f) What can be said about the rate at which electrical energy was being used up in Circuit 2 compared to Circuit 1? Explain why.

(g) What factors related to the energy being released from the dry cell could be identified as changing just by observing the light bulb(s) in both circuits? Explain your answer.

(h) State the factors that affect the amount of energy that can be released from a dry cell.

(i) Why is it important to ensure that both dry cells are completely charged before beginning the investigation? Are there any other aspects of the investigation that could affect the results?

(j) How long would the single light bulb in Circuit 1 remain glowing if two AAA dry cells were connected in parallel instead of just one dry cell? Explain why.

Exploring

1. Visit the web sites for some of the battery manufacturers. Find out how much energy is stored in the different-sized dry cells. Compare the energy stored in the dry cells used in watches and cameras to that stored in the dry cells we have been using.

2. What would have happened to the values of the factors identified in (h) in each circuit if AA dry cells had been used instead of AAA dry cells? Explain why.

3. When would you choose to use D dry cells rather than AAA dry cells if you were designing a flashlight? Explain why. Why are AAA dry cells sometimes used in flashlights?

Reflecting

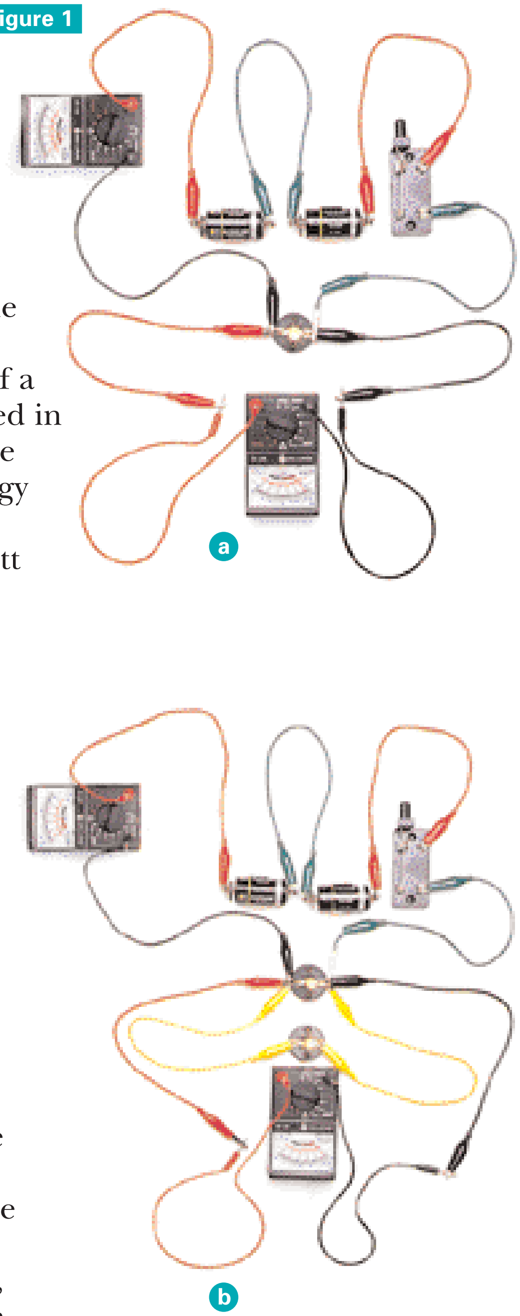
4. What advantages are there in having an energy source such as a dry cell where the voltage drops gradually as it nears complete discharge? What disadvantages could there be?

11.2

Measuring Electrical Energy

What size dry cells does your CD player or tape cassette player need? How many of them are used? How long does one set of cells last? All these questions relate to the amount of electrical energy that can be released by the battery to operate the device. **Energy** is defined as the ability to do work. **Electrical energy** may be defined as the energy transferred to an electrical load by moving electric charges. The symbol for electrical energy is E, and the SI unit used for measuring energy is the **joule**. One joule represents a very small amount of energy—enough, for example, to light a 100-W light bulb for only a hundredth of a second. Because the joule is so small, energy is also measured in larger units such as the **watt hour** and the **kilowatt hour**. The watt hour is 3600 times larger than a joule so 1 W·h of energy would light a 100-W light bulb for 36 seconds. As the name indicates, the kilowatt hour is 1000 times larger than the watt hour.

Figure 1



Three Factors Determine the Amount of Electrical Energy

Observing Sample Circuits

What factors determine the amount of energy in a battery? Observing the circuits in **Figure 1** will help you find out. In **Figure 1a**, a single 15-Ω light bulb is connected to a 3-V battery. The voltage drop across the light bulb is 3 V. Using Ohm's law, the electric current is 0.2 A (3 V/15 Ω). After the switch is closed, the light glows brightly for about 5 h, and then within a few minutes stops glowing altogether.

In the second circuit (**Figure 1b**), an identical light bulb is connected in parallel with the first bulb. The voltage drop across the bulbs in the second circuit is also 3 V. The same amount of current (0.2 A) will flow through *each* of the two light bulbs, so now the total current is 0.4 A, twice the amount that flowed in the first circuit. As you would expect, the bulbs will glow for only about 2.5 h before the energy in the battery is used up.

Voltage Drop, Electric Current, and Time

The same-sized battery is used in each of the sample circuits, so the amount of energy supplied by each battery is also the same. When we consider the two circuits, there appear to be two quantities that are directly related to the battery in each case. The first is the voltage drop (V), which is a measure of the energy *each* electric charge gave up as it moved through the circuit. The second quantity is the electric current (I) itself, which is a measure of the rate at which the electric charges flowed out of the battery. However, there is a third quantity—the time (Δt) that the electric charges were flowing in the circuit while the bulb was glowing. In fact, all three quantities need to be considered to account for the energy released by the battery to the circuit.

Calculating the Amount of Electrical Energy

If you multiply the voltage drop, electric current, and time interval together for each circuit, the answer is the same for both circuits. The answer represents the energy given to the circuit by the battery. (The time is multiplied by 3600 to convert from hours to seconds.)

Circuit 1 $V \times I \times \Delta t = 3\text{ V} \times 0.2\text{ A} \times (5.0\text{ h} \times 3600\text{s/h}) = 10\,800\text{ J}$

Circuit 2 $V \times I \times \Delta t = 3\text{ V} \times 0.4\text{ A} \times (2.5\text{ h} \times 3600\text{s/h}) = 10\,800\text{ J}$

If you connect this battery to any type of electrical load until it is discharged, measure these three quantities, and multiply them together, you always get approximately the same number. This simple relationship can be used to calculate the amount of energy released from a battery into an electrical load.

Scientists express this relationship in the form of a formula:

Electrical Energy = Voltage Drop × Electric Current × Time Interval

This can be written using the symbols for the quantities:

$$E = V \times I \times \Delta t$$

Where E is the electrical energy measured in joules (J)
V is the voltage drop measured in volts (V)
I is the electric current measured in amperes (A)
and Δt is the time interval measured in seconds (s)

Although the correct SI unit for energy is the joule (J), it is not a very practical unit for measuring electrical energy in everyday use. When we use electrical devices, we usually measure the time in minutes and hours, not seconds. Consequently, electrical energy is also measured in other more convenient units such as the watt hour (W·h)for batteries and the kilowatt hour (kW·h) for the much larger amounts used by clothes dryers and refrigerators. The 10 800 J of energy released from the batteries in the examples above is actually only 3 W·h if you measure the time in the more practical unit of hours.

Sample Problem: Calculate the energy released from a battery in a flashlight bulb that was switched on for 4.5 h, in which the voltage drop was 6 V, and the current flowing through the bulb was 0.35 A.

Data:
Electrical energy = ? W·h
Voltage drop = 6 V
Electric Current = 0.35 A
Change in Time = 4.5 h
= 16 200 s

Equation (time in seconds):
$E = V \times I \times \Delta t$
$E = 6\text{ V} \times 0.35\text{ A} \times 16\,200\text{ s}$
$E = 34\,020\text{ J}$
The energy released from the battery is 34 020 J.

Equation (time in hours):
$E = V \times I \times \Delta t$
$E = 6\text{ V} \times 0.35\text{ A} \times 4.5\text{ h}$
$E = 9.45\text{ W·h}$
The energy released from the battery is 9.45 W·h.

Determining Energy Capacities of Dry Cells

Many people buy a battery charger (**Figure 2**) and invest in rechargeable batteries. In the long term, it is more economical and better for the environment. You can calculate how much energy is stored in a cell or battery by using information in data tables that are provided on battery manufacturers' web sites. The information in **Table 1** is only a small sample of what can be found there.

Figure 2

Table 1

Duracell Product Number	Size	(Nominal) Voltage (V)	Rated Capacity (A·h)
MN 1300	D	1.5	15.000
MN 1400	C	1.5	7.800
MN 1500	AA	1.5	2.850
MN 2400	AAA	1.5	1.150
MN 908	Lantern	6.0	11.500
MN 918	Lantern	6.0	24.000
MN 1604	9 volt	9.0	0.580

Notice that the amount of electrical energy each cell produces is not listed. The table simply provides the voltage and the rated capacity for each cell. You can use the equation you have just learned and these two quantities to calculate the electrical energy of each cell, since the **rated capacity** is simply the electric current multiplied by the time interval. In other words:

Since Electrical Energy = Voltage Drop × Electric Current × Time Interval

and Electric Current × Time Interval = Rated Capacity

then Electrical Energy = Voltage Drop × Rated Capacity

or $E = V \times I \times \Delta t$

Sample Problem: Using information from an Internet web site, calculate the energy available in a single 1.5-V AA cell that has a rated capacity of 2.8 A·h.

Data:
Electrical Energy = ? W·h
Voltage = 1.5 V
Rated Capacity = 2.8 A·h

Equation:
$E = V \times I \times \Delta t$
$E = 1.5\ \text{V} \times 2.8\ \text{A·h}$
$E = 4.2\ \text{VA·h} = 4.2\ \text{W·h}$
The energy available in a single AA cell is 4.2 W·h.

Challenge

Calculate the amount of electrical energy for the devices you will refer to in the challenge you have chosen.

Understanding Concepts

1. Define the term "electrical energy" and state its SI unit and symbol.
2. List the three factors that determine the electrical energy transferred to an electrical load.
3. (a) Calculate the energy released from a battery in a hand vacuum cleaner that was switched on for 45 s. The voltage drop was 6 V, and the current was 0.30 A. (Answer in joules.)
   (b) Calculate the energy released from a portable radio using a 9-V battery. The current was 0.5 A, and it operated for 2.5 h. (Answer in watt hours.)
   (c) Calculate the energy available in two 1.5-V AAA cells that have a rated capacity of 1.15 A·h.

Making Connections

4. Some models of portable tape players use different-sized cells. Suggest reasons why.
5. When you buy a new electrical device that uses batteries, what questions should you ask about energy usage? Where could you find the answers to your questions?
6. Which dry cells do you think are less harmful for the environment —disposable or rechargeable? Give supporting evidence for your opinion.

Exploring

7. Check the manual of a CD player or cassette tape player. Compare the operating time for disposable dry cells to rechargeable cells. Why do you think there is such a difference?

Reflecting

8. How is it possible for two circuits, each using the same-sized battery, but with a different electrical load, to release the same amount of electrical energy?

Energy When You Need It Most

In some cases when a cell or battery eventually becomes discharged, it may cause a serious safety hazard. Think about the emergency lights at the critical places in the corridors of your own school or in large stores. Find out how they work. In this activity, you will identify battery-operated devices that can cause significant inconvenience or safety hazards when the battery becomes discharged. You will also identify the types of cells and batteries used in these devices, and determine the amount of energy stored in them.

Materials

- tables of data on the performance characteristics of batteries obtained from Internet web sites
- information from user manuals related to the operation, performance, and safety considerations of the devices being analyzed

Procedure

1 In a group make a list of all the commonly used electrical devices that are battery operated such as the clock shown in **Figure 1**. They can be in the home or other kinds of buildings, in vehicles, or carried with you or attached to you. From the list, identify those devices that can cause inconvenience or pose a safety hazard if the batteries become discharged at an inopportune time.

2 (3A) Carry out research on the Internet and in your library to obtain information about the types of cells and batteries in the devices identified in step 1, and the amount of electrical energy stored in them.

(a) Design and choose a method to summarize and present the important data you have found, and the results of the calculations you will be completing.

3 Calculate the amount of electrical energy in each cell or battery using the energy equation and the information you have obtained.

(a) Enter any important information and the results of your calculations in the table.

4 Consider the way that you presented your findings.

(a) Were there any limitations in using the format you chose to present all the information you found?

5 Summarize your findings.

(a) What safety recommendations will you include?

Figure 1

Making Connections

1. List four devices in which the unanticipated discharge of the battery (cell) could cause a safety hazard. Brainstorm possible solutions to overcome this hazard.

Exploring

2. List the web sites you visited. Rate their usefulness and justify your evaluation.

11.4

The Rate at Which Energy Is Used

Although you may not have previously understood what electrical power was, you have been using the units of electrical power in your everyday speech for most of your life. You probably use a 40-W light bulb in your bedside lamp. CD players usually operate on less than 1 W. Electric heaters often have much larger power ratings, which are more conveniently measured in **kilowatts** (1 kW = 1000 W), rather than watts. A typical electric space heater may have a power rating of 1500 W, or 1.5 kW. **Table 1** shows the power rating of some electrical appliances.

When we think about electrical power, we are thinking about how rapidly an appliance is using up electrical energy. A 300-W bulb uses up three times as much electrical energy as a 100-W bulb in the same amount of time. When you are in a car travelling at a speed of 100 km/h, you are travelling over the road at a rate of 100 km in one hour. Speed is a measure of the rate at which you are covering the

Table 1 **Power Ratings of Common Appliances**

Appliances	Average Power (W)	Monthly Energy Use (kW·h)	Approximate costs ($)
air conditioner (room)	750	90–540	7.20–43.30
clothes dryer	5000	50–150	4.01–12.03
coffee maker	900	4–27	0.32–2.17
computer (monitor & printer)	600	5–36	0.40–2.89
electric kettle	1500	3–15	0.24–1.20
lighting – 60-W incandescent lamp	60	5–30	0.40–2.41
microwave oven	1000	5–20	0.40–1.60
television – colour	80	5–15	0.41–1.20
toaster	1000	1–5	0.08–0.41

Costs are based on $0.082 per kW·h.

Try This Checking Registration Plates

If you look at the registration plate on any electrical device (**Figure 1**), you will always see at least two of the three quantities, voltage (V), current (I), and power (P) listed. This is a legal requirement of the Canadian Standards Association (CSA). It is an important part of the electrical safety regulations set up by the Canadian government to protect consumers.

Figure 1

Why are only two of the three quantities required to be listed? Which one is most commonly omitted? Why?

Draw the table shown below and list at least 15 electrical devices. Then locate the registration plate on a sample of each of the devices in your list, and complete the table by doing the appropriate calculation.

Only look at the registration plate if the device is disconnected to avoid danger of electric shock.

$$P = V \times I$$

Appliance	Electrical Power (P) (W)	Voltage Drop (V) (V)	Electric Current (I) (A)
?	?	?	?
?	?	?	?

distance. The word "rate" often involves how much a quantity is changing in a given time interval. **Electrical power** is a measure of the rate at which electrical energy is being used. The symbol for electrical power is P. The metric SI unit for electrical power is the **watt**, and the symbol is W.

Calculating Electrical Power

Electrical power can be calculated using the simple formula shown below. Just as speed is calculated by dividing distance by the time interval, electrical power is calculated by dividing electrical energy by the time interval.

$$\text{Electrical Power} = \frac{\text{Electrical Energy}}{\text{Time Interval}}$$

Symbolically,

$$P = \frac{E}{\Delta t}$$

Where E = electrical energy measured in joules (J)
P = electrical power measured in watts (W)
Δt = time interval measured in seconds (s)

Sample Problem: Calculate the power of a toaster that uses 72 000 J of energy in 50 s.

Data:
Electrical energy = 72 000 J
Time interval = 50 s
Power = ? W

Equation:

$$P = \frac{E}{\Delta t}$$

$$P = \frac{72\ 000\ \text{J}}{50\ \text{s}} = 1\ 440\ \text{W} = 1.440\ \text{kW}$$

The electrical power of the toaster is 1440 W (1.440 kW).

The formula for electrical power shown above is rarely used in practice because you have to measure both the energy and the time interval to be able to solve the formula. The formula normally used to calculate the power of an electrical device consists of two quantities that you have already measured many times in this unit—voltage drop and electric current:

Electrical Power = Voltage Drop × Electric Current

$$P = V \times I$$

This formula can be derived from what you already know:

$$P = \frac{E}{\Delta t} \quad \text{and} \quad E = V \times I \times \Delta t \quad \text{so} \quad P = \frac{V \times I \times \Delta t}{\Delta t}$$

The time interval (Δt) divides out, leaving

$$P = V \times I$$

Sample Problem: Calculate the power of a vacuum cleaner if the operating voltage is 120 V, and the current flowing through it when it is used is 7.90 A.

Data:
Power = ? W
Voltage = 120 V
Current = 7.90 A

Equation:

$$P = V \times I$$

$$P = 120\ \text{V} \times 7.90\ \text{A}$$

$$P = 948\ \text{W} = 0.948\ \text{kW}$$

The power rating of the vacuum cleaner is 948 W, or 0.948 kW.

Understanding Concepts

1. (a) Define the term "electrical power."
   (b) State the SI unit and symbol for electrical power.
2. What electrical quantities related to power are listed on the information plates of electrical appliances? Why aren't the energy and time listed there instead?
3. (a) Calculate the power rating of an electric toaster that uses 210 000 J while toasting bread for 140 s.
   (b) Calculate the power rating of a coffee grinder that operates on a voltage of 120 V. A current of 1.7 A flows in the motor.

Making Connections

4. If you wanted to plug two or more appliances into a wall outlet, how could you use the data on the appliance information plates to find out how much total current would be drawn from the outlet when they were all plugged in?
5. Locate all the electrical appliances and devices in the kitchen and calculate the total power rating. How many wall outlets would you need to plug them all in and not overload any of the 15-A circuits?

Reflecting

6. If electrical energy did not exist, what would we have had to use in its place in our homes?

Challenge

How can you make others aware of the importance of power ratings and how they relate to energy conservation?

11.5

Electrical Energy

How would your lifestyle change without electrical energy? Electricity is clean, relatively easy to transmit long distances, and can be converted into the other forms of energy we need in our everyday lives.

Because electrical energy is essential, scientists and engineers are constantly trying to develop new technologies to produce even more of it. The whole world's use of electrical energy is always increasing. In our investigations so far, we have been using only energy sources that produce relatively small amounts of electrical energy—dry cells and batteries. Now we are going to study ways to produce the huge amounts of electrical energy required to supply the constantly growing needs of our modern society.

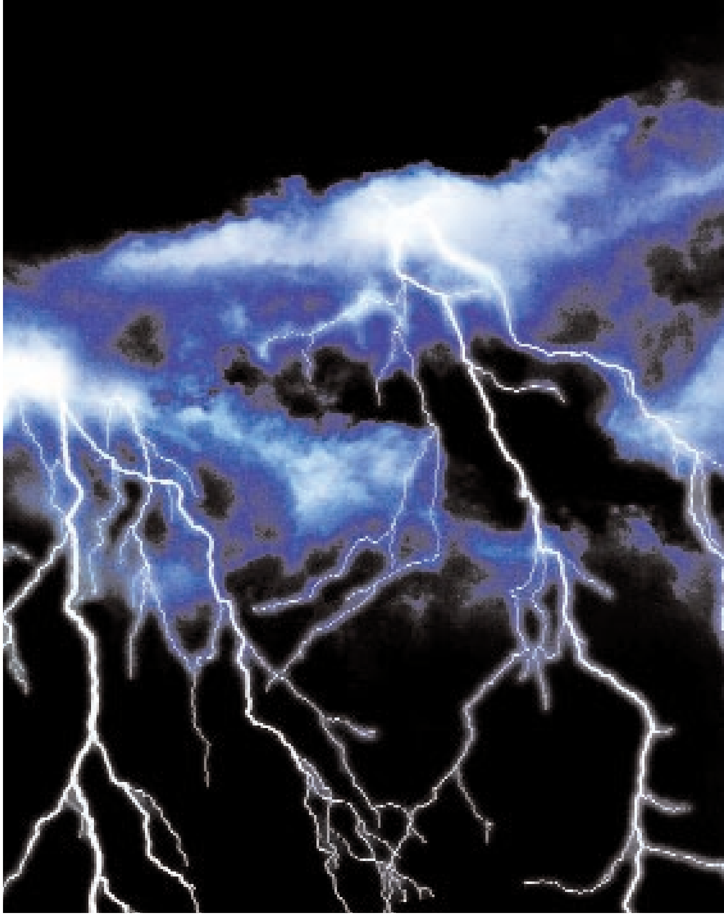


Figure 1

Sources of Electrical Energy

The only large source of electrical energy that is produced naturally is lightning (**Figure 1**). Unfortunately, no one has yet found a way to control lightning or a way to store the huge amounts of energy that are released in a few fractions of a second. An additional problem is that it occurs quite randomly, and in some areas of the world lightning hardly occurs at all. Clearly, other energy sources must be used to produce the constant, reliable supply of electrical energy we need.

It would be preferable to use **renewable energy resources** to generate electrical energy because such resources constantly replenish themselves. Solar energy, energy from the wind, biomass, and—as long as there are no droughts—the gravitational potential energy of water stored behind a dam or from a waterfall are examples of renewable energy resources. Unfortunately, at the present time it is not possible to satisfy all the energy needs of our society using renewable resources. Instead, we use large amounts of **nonrenewable energy resources**, such as fossil fuels and nuclear fuels. One of the major disadvantages of using nonrenewable resources is that they cannot be replaced in a reasonable amount of time, such as a human lifetime.

Did You Know ?

After including the energy losses that occur when converting fossil fuels into electrical energy at the generating station, the ordinary incandescent light bulb converts only about 1% of the original fossil fuel energy into visible light.

Try This: Sources of Electricity

Prepare a table with the following headings:

Source of Electricity	Renewable or nonrenewable	Advantages	Disadvantages	Ways to Improve

As we study the various ways of generating electricity, add information to this table so you will have a summary that will allow you to make comparisons and suggestions about the various ways of generating electricity.

Environmental Concerns and Sustainability Issues

A growing concern is the need to produce electrical energy without harming the environment. In addition, the economic and societal risks and benefits related to each kind of energy resource should be considered. This process applies just as much to the generation of small amounts of electrical energy in such energy sources as batteries as it does to the large-scale production in generating stations. To properly evaluate those risks and benefits, we need to consider all the major aspects of the production and use of electrical energy: where and how it is generated; where and how it is transmitted from the generating station to the place where it is used; and, finally, how it is converted into other forms of energy for different consumers.

The needs of society have to be balanced with the negative impacts of pollution produced during the generation and use of electrical energy. A particular concern is the limitation and reduction of carbon dioxide (CO_2) emissions from fossil fuels as a means of reducing global warming.

The term **sustainability**, when we are discussing electrical energy, refers to a consideration of the social, economic, and environmental aspects of its production and use, now and into the future. The production of electrical energy, now and in the future, should not place an increased burden on our environment or require the unsustainable use of nonrenewable energy resources.

In the following sections, you will learn about various aspects of the production, transmission, and conversion of electrical energy. The amounts of electrical energy will range from the extremely small, such as the amount generated when you push your debit card into a banking machine (**Figure 2**), to the huge amounts required to operate all the street lights in a big city. Think about the issues mentioned above as you develop a deeper understanding of the generation, transmission, and use of electrical energy.

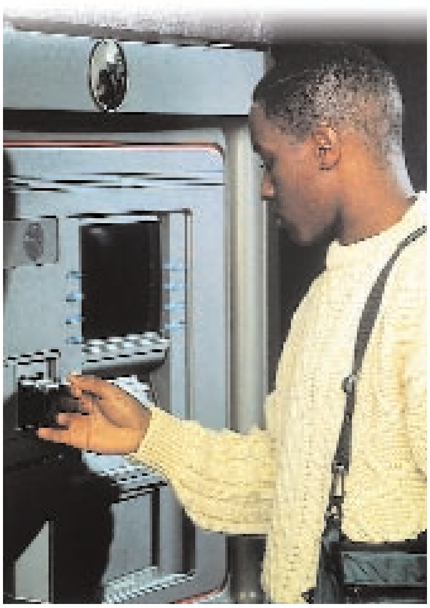


Figure 2

Understanding Concepts

1. Describe some of the advantages of using electrical energy.
2. Why don't we try to capture the huge amounts of electrical energy available in lightning?
3. Compare the use of renewable and nonrenewable energy resources for producing electrical energy. List at least two examples of each kind of energy resource.
4. Define the term "sustainable" and explain its importance in terms of the production of electrical energy.

Making Connections

5. Why is the use of electrical energy increasing?
6. What negative impacts could occur as a result of increased production of electrical energy throughout the world?

Exploring

7. (3A) Use the Internet, CD-ROMs, or the library to determine when and where the first mass electrification system was installed in North America. Who did it? Was this system the one adopted by all the other electrical distribution companies? Describe the system's first 20 years.

Reflecting

8. What measures has your family used to try to conserve the use of electrical energy? Begin to think about practical ways that you might be able to reduce your use of electricity. Record your suggestions so that you can share them later.

Challenge

What question would you ask to assess someone's understanding of renewable and nonrenewable energy resources and their significance in relation to sustainability?

Automobiles and the Fuel Cell

In North America, names like Ford, Stanley Steamer, and Detroit Electric were important to the early development of the automobile. Henry Ford used the internal combustion engine to drive the first automobiles his company produced, and it is still used in cars today. However, some of the early cars used steam power, like those produced by Stanley. Other manufacturers, such as Detroit Electric, used electricity. In the early 1900s, first the steam-driven automobile and then the electric automobile far exceeded the gasoline-powered car in popularity. In fact, in 1912 there were 30 000 electric cars on the road in the United States with 6000 new ones produced each year.

(a) Why did steam-driven and electric automobiles disappear from car dealerships over the years?

(b) On which continent did the internal combustion engine increase in popularity most rapidly? Explain why.

The Development of Modern Electric Cars

The size and mass of the batteries needed to allow an electric car to travel a reasonable distance before the batteries need to be recharged are problems that have been difficult to overcome. Electrically powered delivery vans, for instance, can be run within a city, but they cannot take longer trips to other urban centres. Many manufacturers are now trying to overcome this problem because the internal combustion engine produces environmental pollution and uses nonrenewable resources.

General Motors is testing a “hybrid” diesel-electric bus for city streets. The bus uses 40% less fuel and produces less pollution than diesel- or gasoline-powered buses. The wheels of the bus are driven by electric motors operated by batteries. A large set of batteries is charged by a diesel-powered engine that is about half the size of the engine normally used. The engine, which runs at a more economical rate, keeps the batteries fully charged. A city bus normally gives off the most pollution when it accelerates after its many stops. The engine in the hybrid bus runs at a constant rate, avoiding this problem.

Many manufacturers, including Daimler-Chrysler, Ford, General Motors, Honda, Nissan, and Toyota, began introducing these vehicles in the late 1990s. But, because they still use fossil fuels and produce some pollution, they are not ideal replacements for the cars we are familiar with today.

(c) Summarize the problems that must be overcome to produce a practical electrically powered automobile.

(d) What are the advantages of “hybrid” vehicles compared with those using internal combustion engines?

(e) Why are hybrid vehicles not permanent solutions to the replacement of the internal combustion engine?

Fuel Cells: A Practical Solution

Governments in Canada and the United States have passed laws that require automobile manufacturers to drastically increase the efficiency of their vehicles, while at the same time, reduce pollution.

Figure 1
A city bus powered by a fuel cell

The future for electric vehicles appears to depend on **fuel cell** technology (**Figure 1**). Most advances in this field are being made in Canada. For example, Ballard Power Systems is working with automakers to produce an energy system known as the proton exchange membrane fuel cell (**Figure 2**). The fuel cell, which operates silently, requires a continuous supply of hydrogen and oxygen to produce electricity electrochemically without combustion. In the fuel cell, the hydrogen, obtained from natural gas or methanol, is combined with oxygen from the atmosphere to produce the electricity. Water vapour and heat are the only byproducts of the process. A single fuel cell consists of a positive plate called the **anode** and a negative plate called the **cathode** which is coated with a thin layer of platinum. Electrons are produced at the anode of the fuel cell and travel as a normal electric current through the electrical load in the circuit. The protons from the hydrogen gas migrate through a proton exchange membrane inside the fuel cell that separates the two electrodes. When the protons reach the cathode, they combine with oxygen from the air and with the electrons returning from the external circuit to form water and heat. Individual fuel cells are placed together in the number needed to form a fuel cell battery.

(f) What have governments done to encourage manufacturers to produce electric automobiles?

(g) What technological breakthroughs have occurred to make it possible for a car to run solely on electricity?

(h) Why is the fuel cell preferred over the existing alternatives for driving vehicles?

A Versatile Energy Source

There are other potential uses of the fuel cell. They include electrical generators the size of refrigerators that run on natural gas and could provide electrical energy for isolated buildings. This would be especially valuable in remote communities. In addition, small portable units are being developed to operate such devices as hedge clippers and portable telephones.

Fuel cells can even be operated by the methane produced in sewage treatment plants and landfill sites around the world.

Making Connections

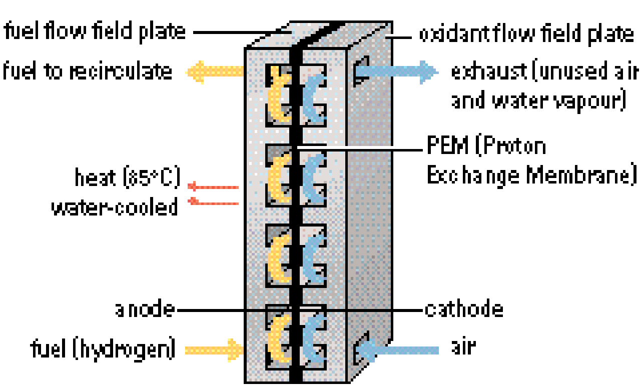
1. Brainstorm a list of other practical applications for fuel cell technology.

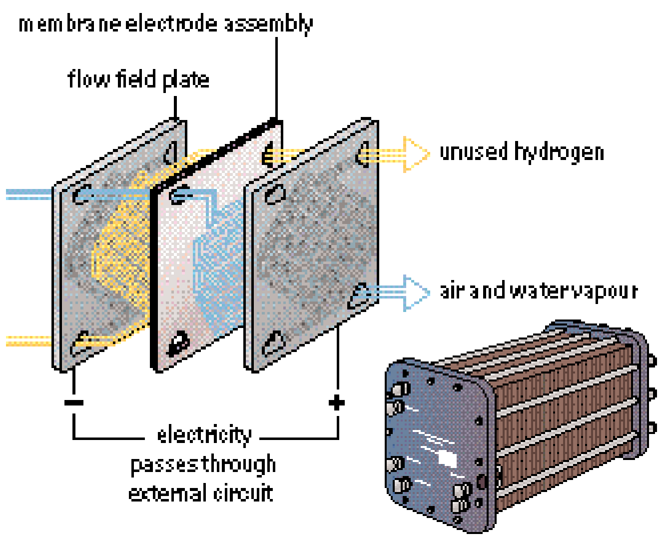
2. What other raw materials could be used to provide the hydrogen required to operate the fuel cell? Suggest how this could be useful on farms and in isolated areas.

Exploring

3. (3A) (3B) Research on the Internet and in the library to find out more about fuel cells and other proposed electrochemical sources of electrical energy. Is the fuel cell the best alternative for all applications? What are its disadvantages? Write a brief position paper supporting your viewpoint.

Figure 2





11.7 Investigation

SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ● Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Energy Transformations

All forms of energy can be converted into electrical energy. Several energy transformations are needed when using fossil fuels or nuclear energy to produce large amounts of electricity. However, we have developed a number of devices that produce small amounts of electrical energy by both direct and indirect conversion. Your studies with dry cells have shown how chemical energy can be directly converted into electrical energy. Now let's investigate some energy conversions, using forms of energy other than chemical energy.

In this investigation, you will study examples of the conversion of several different forms of energy into electrical energy.

Question

How can it be demonstrated that an energy conversion from a given form of energy into electrical energy has occurred?

Hypothesis

If we can measure or identify the flow of electric charges when using only one form of energy in conjunction with an energy converter, or transducer, it can be inferred that the original form of energy has been converted into electrical energy.

Materials

- switch
- connecting wires
- photoelectric cells (photocells or solar cells)
- light bulb and holder
- light source (bright)
- barbecue lighter (equipment containing piezoelectric crystals)
- thermocouples
- voltmeter
- Bunsen burner
- microphone
- oscilloscope
- length of wire (2 m), plus cardboard tube
- ammeter
- permanent bar magnet

Your teacher may provide other materials and equipment:

- hand-operated generator or bicycle generator
- computer, with various types of sensors

Procedure

Complete each part of the investigation as instructed by your teacher.

Always connect and disconnect electrical equipment by the plug to avoid danger of electric shock.

Part 1

1 Design a circuit to measure the current flowing from the photoelectric cells through the bulb, and also measure the voltage drop across the bulb. Construct the circuit and insert the light bulb into the holder. Ask your teacher to inspect your circuit before continuing. Close the switch and shine a bright light onto the photoelectric cells. Draw a schematic diagram of the circuit.

(a) Record your observations.

2 Move the light source you are using to within a few centimetres of the surface of the photoelectric cells, then slowly move it away to a distance of approximately 1 m.

(a) Record your observations.

Disconnect the circuit completely before moving to the next activity.

Light source may be hot. Handle with caution.

Part 2

3 Squeeze the barbecue lighter several times, using a different force each time.

(a) Record your observations.

Part 3

4 Connect the wires from the thermocouple to the voltmeter.

5 Light the Bunsen burner.

Tie back long hair and remove loose jewellery.

6 Hold the joined end of the thermocouple in the flame and observe the voltmeter. Move the joined end in and out of the flame.

(a) Record your observations.

Part 4

7 Connect the leads from the microphone to the oscilloscope (as instructed by your teacher).

8 Speak into the microphone and observe the oscilloscope display screen. Vary the loudness of your voice and the distance of your mouth from the microphone.

(a) Record your observations.

Part 5

9 Wrap the wire in a coil around the length of the cardboard tube, leaving about 15 cm at each end unwrapped to attach to the ammeter. (Ensure that if the wire is varnished, the ends of the wire have the varnish removed using sandpaper.)

10 Attach the ends of the coil of wire to the ammeter. (Your teacher will tell you which current scale to use.)

11 Move the north pole of the permanent magnet in and out of the coil of wire at a steady rate, and observe the ammeter.

(a) Record your observations.

12 Repeat step 11, but move the magnet back and forth at different speeds.

(a) Record your observations.

13 Predict what will happen if you repeat steps 11 and 12 using the magnet's south pole.

(a) Record your predictions.

14 Repeat steps 11 and 12 using the magnet's south pole.

(a) Record your observations.

Analysis and Communication

15 Analyze your observations by answering the following questions in a table:
6D

(a) Identify the form of energy that was converted into electrical energy in each part of the investigation, and also the device used to do the energy conversion.

(b) What effect was produced when the bright light source was moved close to and away from the photocells? Explain what caused this effect.

(c) Calculate the maximum power produced by the photoelectric cells.

(d) Explain the variations in the amount of electrical energy produced when using the barbecue lighter.

(e) What temperature range is a thermocouple most suitable for measuring? Explain why.

(f) Explain the variations in electrical energy produced by the microphone. Comment on any differences between your voice patterns and that of other class members.

(g) Describe the various ways you can change the amount of electrical energy produced by moving the magnet in and out of the coil. What happens if you move it along the outside the coil?

(h) Predict what would happen if you repeated steps 11, 12, and 14 at the other end of the coil. Try it and comment on your predictions.

Making Connections

1. List two examples of the practical use of each kind of energy converter that was used in the investigation.
2. What factors might limit the amount of electrical energy produced by photoelectric cells if they were used to produce electricity for a house?

Exploring

3. Identify as many examples as possible in our everyday lives where magnetic materials or strips produce electrical energy. What must be happening for the magnetic materials to produce the energy?

SKILLS HANDBOOK: 6D Creating Data Tables

11.8

Small-Scale Generation Methods

Electrical energy could almost be called the "in-between" form of energy. First, other forms of energy are converted into electrical energy in electrical generating stations. Then it is converted to other forms of energy for a variety of uses. For instance, an electric kettle heats water, a television produces both light and sound energy, and an electric fan produces mechanical energy that is used to turn a fan blade.

Electrical energy has many positive features: it is clean; it can easily be transmitted large distances; it can travel through conductors around corners, underground, and even underwater; and it is safe to use if the proper precautions are taken. However, perhaps its major advantage is that it can be produced from all other forms of energy and can then be converted back into all of them, except nuclear energy and the fossil fuel form of chemical energy.

Producing Electrical Energy Directly from Other Forms of Energy

There are five basic forms of energy that can be used to produce electrical energy directly from the source of energy. They are mechanical, thermal, sound, radiant (light, radio, microwave, solar), and chemical energy.

Mechanical Energy

Mechanical energy can be directly converted into electrical energy. When certain types of quartz crystals are subjected to stress by being squeezed or stretched, small amounts of electrical energy are produced. This effect is called the piezoelectric effect. The quartz crystals used in watches produce a very small electrical signal that controls the operation of the watch. Piezoelectric crystals are also used in some types of microphones and for producing the spark from a barbecue lighter.

Did You Know

Earthquakes in Japan have produced lightning in areas where the ground contains large amounts of quartz. Lightning bolts several metres long have been observed shooting out of the ground as the quartz crystals have been subjected to huge changes in pressure during the earthquake.

Thermal Energy

Thermal energy can be converted into electrical energy using a device called a thermocouple. The thermoelectric effect occurs when two different metals are joined together at the ends, as shown in **Figure 1**, and the junction of the two metals is heated. Thermocouples are usually used to measure higher than normal temperatures.

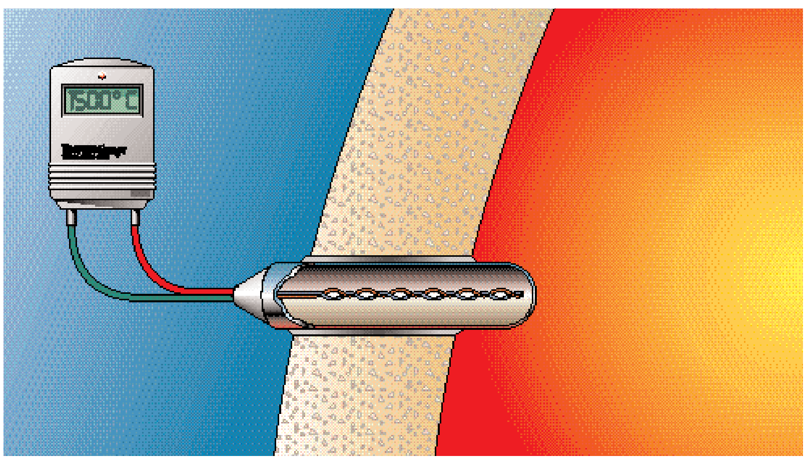


Figure 1

Sound Energy

Every time you use the telephone, you are producing electrical energy as you speak into the mouthpiece. Microphones of one kind or another are so much a part of our lives that we just take them for granted. The music we listen to and the movies and television shows we watch all required the conversion of sound energy to electrical energy when they were being recorded. Special microphones called geophones are used by geologists to investigate the transmission of vibrations through the ground when they are prospecting for minerals.

Radiant Energy

Whether you call them photovoltaic cells, photoelectric cells, solar cells or just photocells, they are becoming increasingly important as a versatile source of electrical energy. **Photoelectric cells**, like the ones in **Figure 2**, convert light energy directly into electrical energy. When light strikes the surface of certain materials such as silicon, electrons are released and produce an electric current. In effect, the photoelectric cell is a light-energized cell. However, instead of using chemical energy to provide the electric charges with energy, as a cell normally does, the photoelectric cell uses light energy.

Large flat surfaces covered with photoelectric cells are used to provide the electrical energy required by spacecraft and satellite equipment. Photoelectric cells are used as barcode readers at supermarket checkout counters, for operating automatic doors, and for automatically switching on streetlights at dusk. Your CD player uses a photoelectric cell to detect the variations in the intensity of laser light reflected from the pitted surface of the disk. Currently, photoelectric cells cost too much for use as a large-scale generator of electrical energy. However, costs are decreasing, and their performance is constantly improving. As renewable energy resources become increasingly important, photoelectric cells will become one of the major sources of electrical energy.

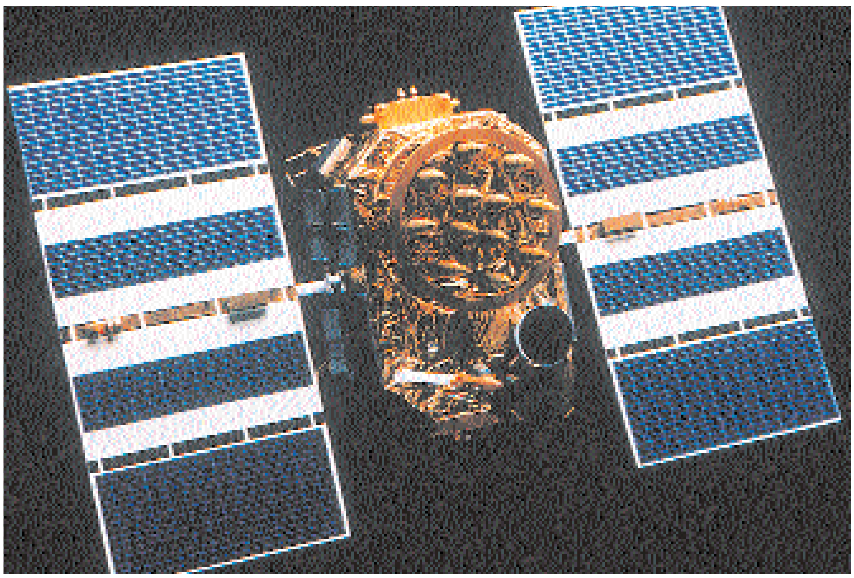


Figure 2
Photoelectric cells

Chemical Energy

You have already become familiar with two devices that convert chemical energy into electrical energy—the voltaic cell and the fuel cell. The two major types of voltaic cells, primary cells and secondary cells, were discussed in Chapter 10. More information about some of these very versatile energy sources is outlined on the next page.

The Primary Cell: A Disposable Energy Source

Many wristwatches today are digital and use small, specially designed dry cells. There are actually dozens of different-sized, special purpose dry cells available. The devices in **Figure 3** use dry cells made of special materials to suit each special requirement. Many electrically operated devices, such as wristwatches, calculators, and cameras, contain computer chips or special circuits that will operate correctly only if the voltage of the battery stays at a certain value. When the voltage drops below the critical value, the circuit will not operate. Special batteries have been designed so that the voltage remains constant until it is almost completely discharged, then within a few minutes, the voltage drops so low that the device just stops working. The original miniature batteries for these devices contained mercury, but their disposal is hazardous to the environment. Newer batteries are made with zinc and silver oxide.

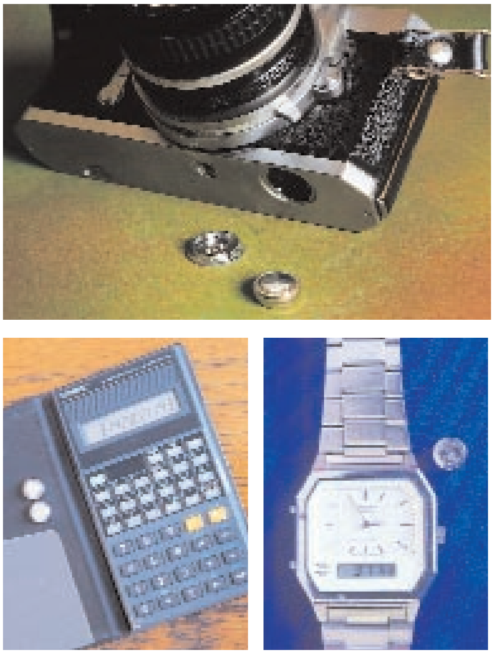


Figure 3

The Secondary Cell: A Rechargeable Energy Source

The secondary cell was developed to provide larger amounts of electrical energy more economically than the primary cell. A secondary cell can be discharged and recharged hundreds of times. Although new types of secondary cells have been developed in recent years, the **lead-acid cell** is still a useful source of portable electrical energy. It has been used for many years in car batteries. This cell was developed by Gaston Plante in 1859. To recharge a secondary cell, the chemical change is reversed by connecting the cell to a source of electrical energy, such as a battery charger (or the alternator in a car). As the cell is recharged, the electrical energy from the charger changes the electrodes back to their original state. The electrical energy is converted to chemical energy. Most modern lead-acid storage batteries are sealed to reduce loss of electrolyte by evaporation. The electrolyte is usually in the form of a gel.

Lead-acid batteries are not able to store sufficient energy to operate a practical electric car. Instead, some companies are working with nickel-metal hydride (NiMH) batteries that produce about twice as much energy as lead-acid batteries, are much lighter, and have a life cycle that would allow them to last as long as the car does. In addition, they have no hazardous materials to be disposed of and have superior cold-weather performance. However, they do not operate as well as the lead-acid battery at high temperatures, do not provide as much acceleration performance, and are very expensive.

Did You Know

A common belief is that nickel-cadmium batteries have "memories" and cannot be charged beyond the point where they were recharged the first time. However, manufacturers of these rechargeable batteries indicate that if they are completely drained of all energy once a month, and then recharged, this problem can be largely eliminated.

Smaller Rechargeable Batteries

One of the most reliable portable sources of electrical energy, the nickel-cadmium cell (NiCd), may be charged and discharged hundreds of times while still providing a constant voltage. In cost per hour of use, it is perhaps the most economical secondary cell. Nickel-cadmium cells are used in portable devices such as pocket calculators, electric shavers, electronic flash units for cameras, personal tape players, portable TVs, and many kinds of power tools. Nickel-cadmium cells are less powerful than alkaline cells, do not store well, and will lose about 1% of their charge every day they are not used. They also rely on the world's limited supplies of cadmium and require special disposal because the materials are toxic. Other more powerful (and more expensive) rechargeable cells include those made of nickel-metal hydride, lithium ion (Li-ion), and rechargeable alkaline cells.

Producing Electrical Energy Indirectly from Other Sources of Energy

Another group of small-scale electrical generators requires the use of moving magnets or electromagnets to produce electricity. The movement of magnetic particles when a clerk swipes a credit card, or when signals are produced in a computer from a spinning magnetic hard drive or floppy disk produces tiny amounts of electrical energy. As the magnetic tape moves past the recording heads in tape cassette players and VCRs, varying amounts of electrical energy are also generated.

Fossil fuel-powered electrical generators are available in a wide range of power ratings. These devices require several different energy conversions. The chemical energy in the fuel is converted to heat energy which makes the internal combustion engine turn. Then the spinning shaft of the engine moves magnets or coils of wire in the electrical generator to produce the electrical energy. Building contractors routinely use small, gasoline-powered generators to begin new buildings if the normal electricity supply is not available. When the severe ice storm occurred in Quebec in the winter of 1998, a portable gas generator was often the only reliable source of electrical energy for several weeks for many households. Larger diesel-powered generators are used to produce energy to keep large buildings such as hospitals operating on an emergency basis and to operate diesel-electric locomotives (**Figure 4**).

Figure 4

Understanding Concepts

1. Why can electrical energy be called the "in-between" form of energy?

2. List some of the advantages of electrical energy.

3. Identify the five forms of energy that can be used to produce small amounts of electrical energy, and identify a device that converts each form of energy into electricity.

4. **(a)** Identify the major advantages and disadvantages of producing electricity by photoelectric cells and by using batteries.

(b) Which method of producing electrical energy has the least impact on the environment?

Making Connections

5. **(a)** Describe four practical ways photoelectric cells are used.

(b) Why are they not used to provide the electrical energy needed for our homes?

6. Why are portable fossil fuel-powered generators so useful? What recent developments may be used to replace the smaller versions of these generators?

Exploring

7. (7B) Read reference material related to the discharge characteristics of cells and batteries. On a graph of voltage versus time, draw a line to show how the voltage of an ordinary dry cell changes as the cell discharges. On the same graph, draw a line to show how the kind of dry cell that is used to operate the computer in a camera or a wristwatch would need to discharge.

SKILLS HANDBOOK: (7B) Creating Graphs

Large-Scale Sources of Electrical Energy

About 89% of the energy resources used in Canada are nonrenewable. The remaining 11% is the renewable energy available from falling or running water. Over 80% of the nonrenewable energy resources are in the form of fossil fuels. In order of abundance, oil, natural gas, and coal are the three major fossil fuel resources in Canada. When the chemical energy in fossil fuels is converted into electrical energy, several complete energy conversions are required. The sequences of energy conversions required to produce electrical energy using both nonrenewable and renewable resources are shown in **Table 1**.

Table 1

Sources of Energy Requiring Multiple Conversions

Forms of Energy	Sources of Electrical Energy
chemical and nuclear → heat → mechanical; mechanical (falling water); both → magnetic (electromagnetic generator) → electrical	power station: burning fossil fuel
	nuclear power station
	generator and alternator on car and bicycle
	portable generator using fossil fuels

Nonrenewable Resources

Fossil-Fuel Generating Stations

In a generating station using any of the three forms of fossil fuel as the energy source, the fuel is burned, and the chemical energy released is used to heat water and produce steam (**Figure 1**). In turn, the high-pressure steam is used to turn a set of fanlike wheels called turbines. As the turbine wheels spin, they turn an electromagnetic generator that finally produces electrical energy. In 1997, Ontario obtained about 17% of its electricity from generating stations using fossil fuels.

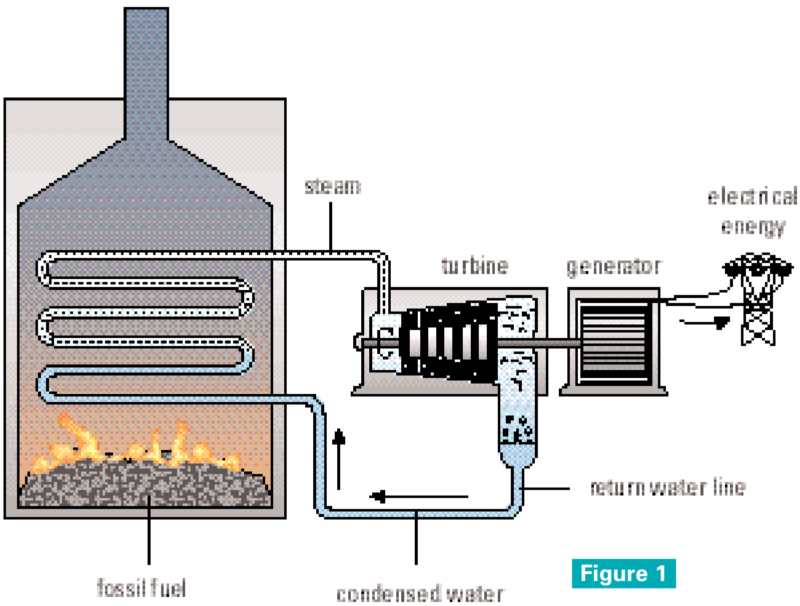


Figure 1

Although transmission lines carry electrical energy across the country, there are communities for which it is not economical to provide electricity in this way. Such communities, often use large diesel generators, like the ones mentioned in section 11.8.

Nuclear Generating Stations

Nuclear energy is also used to generate electrical energy in several parts of Canada. The process is essentially the same as that used with fossil fuels. The basic difference is that, instead of using the chemical energy in the fuel to heat the water, the energy used is that released from nuclear reactions. In 1997, about 48% of Ontario's electrical energy production was supplied by nuclear generating stations.

Did You Know

In 1890, the first windmill to produce electricity began operating in Denmark.

Efficiency of Energy Conversions

When any energy conversion occurs, only part of the original energy is converted into the new form of energy. The waste energy usually ends up as thermal energy. The comparison between the amount of useful energy produced and the original amount of energy used is called **efficiency**. We will discuss efficiency in much more detail in Chapter 12. To conserve energy, it is important to try to make each stage of the production of electrical energy as efficient as possible. **Table 2** lists the efficiency of energy conversion for the different methods of producing electrical energy. A considerable amount of the original energy in the resource is lost in the processes required to produce the electricity at the generating station. Depending on the type of fuel used, only 20% to 26% of the energy contained in the original fuel is converted into electrical energy at the generating station.

Table 2 Electrical Conversions from Nonrenewable Resources

Fuel Used for Generation	Percentage of Energy from Fuel Available as Electricity
nuclear	20.0
petroleum	20.2
natural gas	20.7
coal	22.2
advanced natural gas turbine	26.4

Renewable Resources

Table 3 shows how much of our electrical energy comes from each of the major energy resources. Only 25% is provided by a renewable resource. It is important that we develop large-scale alternative ways of generating electricity from sources that will not run out.

Table 3 Electricity Sources in Ontario

Source of Electricity	Number of Stations	Percentage of Contribution to Total Supply
hydroelectric	69	25
fossil-fuelled	6	17
nuclear	5	48
independent producers or purchased from other utilities	—	10

Hydroelectric Generating Stations

Canada is fortunate to have many locations where it is possible to produce electrical energy by using the gravitational potential energy of falling water. In 1997, about 25% of Ontario's electricity was produced by hydroelectric generating stations. A number of different designs are in operation. Many generating stations store the water behind a dam, which releases the water through special tubes called penstocks, to turn the turbine wheels below (**Figure 2**). Some, such the one at Niagara Falls in Ontario, do not store the water at all. Rather, some of the water falling over the falls is diverted through special tubes to turn the water turbine wheels at the bottom and produce the electrical energy. A third method involves channelling fast-flowing water in a river through a set of turbine wheels to produce the electricity. The generators in the third method are usually used for producing relatively small amounts of electrical energy. The development of small, independent, hydroelectric generating stations has been increasing in recent years.

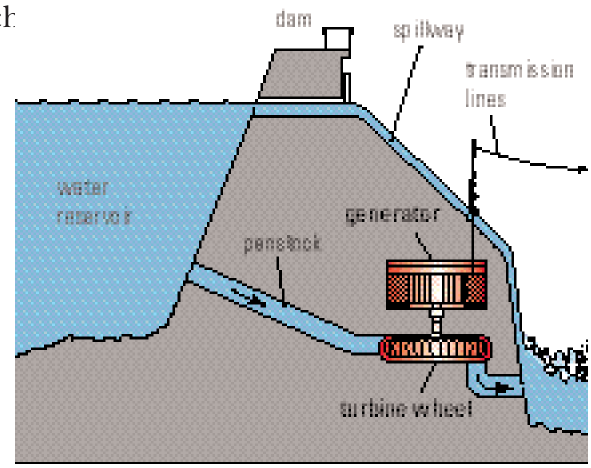


Figure 2
Cross section of a dam

Other Renewable Resources

As the need for an increasing supply of electrical energy becomes more urgent, scientists and engineers are creatively developing new and better sources. Perhaps one of the most promising for widespread use is the photoelectric cell. Continuing research is rapidly improving the efficiency of these devices, as well as lowering the cost of making panels large enough to mount on the roof of a house. The amount of electrical energy used in a home varies from about 20 kW·h to over 80 kW·h per day. Some of the photoelectric panels have a power rating of about 0.25 kW. So if one panel receives four hours of direct sunlight per day, it can produce about 1 kW·h of electricity. One of the major problems with the use of photoelectric cells is the wide variety of weather conditions that exist across Canada, especially in winter.

In fact, most alternative energy sources are somewhat limited in their use because they depend on the conditions at specific locations. Look at the different ways of generating electricity shown in **Figure 3**. Most of these sources are located in places with somewhat unique geographic conditions. However, usually at least one of the alternatives can be applied in almost any location, and by combining the alternatives with the more conventional sources of electrical energy, it is possible to provide a reliable supply of electrical energy.

Figure 3

Constant Production of Electrical Energy

One of the challenges of electrical energy is that it is difficult to actually store it once it has been produced. When you recharge a battery, you are converting electrical energy from an external source back into chemical energy in the battery. Electrical energy itself is not stored in the battery. An electrical device called a capacitor can store small amounts of electrical energy. However, there is no practical way to store the huge amount of electrical energy produced at a generating station.

Because electrical energy produced at a generating station cannot be stored, it must be used up at the same rate as it is generated. As you learned earlier, the rate at which electrical energy is used is called electrical power. Thus, generating stations are often called "power" stations. The output of power stations is usually measured in megawatts (MW). The technical staff at generating stations are constantly adjusting the production of electrical energy to match the amount of energy being used by everyone all across Canada.

One of the most important aspects of any energy conversion used to produce electrical energy is the efficiency of the process, which may be so low that it is not economically worthwhile. **Table 4** provides information on the efficiencies of various alternative energy sources.

Table 4

Electrical Conversions from Renewable Resources

Renewable Source of Electricity	Percentage of Energy Converted to Electricity
solar cells with concentrator lenses	30
single crystal solar cells	23
crystalline silicon solar cells	17
amorphous silicon solar cells	7
electrochemical cells	65
wind generators	30
hydroelectric generators	20

Transmission of Electrical Energy

From generating stations, electrical energy is transmitted along the wires you see suspended from the tall transmission towers that form a huge network across Canada. Often the wires connected between the generating station and the home where it is eventually used are tens, if not hundreds, of kilometres long. Even if the wires are thick and are good conductors of electricity, that length of wire will still have some electrical resistance. When the current flows through the wire, some of the electrical energy will be converted to thermal energy due to the resistance.

The electrical energy losses due to resistance depend on the amount of current flowing in the wires. To reduce the losses, the electrical energy is transmitted using as small a current as possible. By using a special device called a transformer, the voltage of 20 000 V produced at the generating station is increased to over 500 000 V. The increase in the voltage causes a corresponding decrease in the current flowing in the wires and still allows the same amount of energy to be transmitted. However, even when the electricity is transmitted at these high voltages, there are still losses due to the resistance of the wires. Depending on the length of the transmission wires, the total losses due to the transmission of the electricity can amount to about 9% of the energy that left the generating station.

At the other end of the transmission line, the voltage is decreased to 240 V and 120 V for use in your home. So, even before the electrical energy gets into your home, some of the original energy from the energy source was lost producing the electricity, then more of it was lost as it was transmitted to your home. When the electrical energy is used in your home, even more losses occur due to the efficiency of the appliance using the energy.

Understanding Concepts

1. **(a)** List the energy conversions that need to occur when electrical energy is produced from fossil fuels.
   (b) What are the advantages and disadvantages of using fossil fuels?
2. Why is the location of the place where the electricity is generated so important for most kinds of alternative renewable energy resources?
3. Why is the efficiency of the energy conversion from the different energy resources important?
4. Explain why electrical energy needs to be generated constantly.

Making Connections

5. Suggest reasons why Ontario produces more electricity with nuclear energy than with fossil fuels.
6. Why is it important to continue developing smaller, more efficient ways of generating electricity?

Exploring

7. (3A) (3B) Carry out research using the Internet and other sources of information to assess the different methods of producing electricity by nonrenewable energy resources. Which methods seem to be favoured? Has there been a change in perception about which method is most effective in the long term?

Reflecting

8. How might the electrical energy needs of your area be met 50 years from now?

Challenge

Identify alternative sources of energy and the advantages and disadvantages of each.

SKILLS HANDBOOK: (3A) Research Skills (3B) Critical Thinking

Using Renewable Resources

As we have seen, electricity can be generated in a variety of ways from renewable resources. In this activity, you will explore some of the alternative ways that electricity can be generated and compare the relative efficiencies of these methods. Remember that the concept of sustainability must be considered in any plan that is developed.

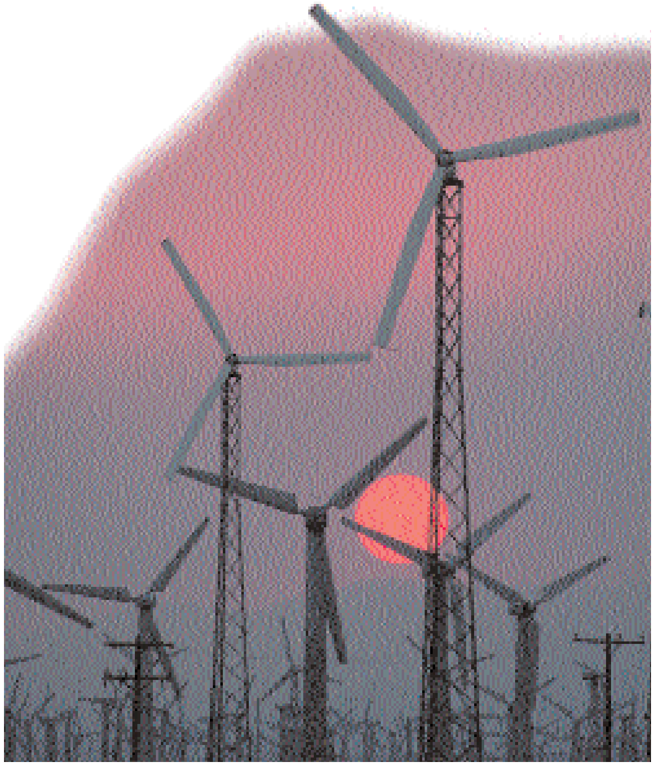


Figure 1

Materials

- Internet access
- CD-ROM encyclopedias and other resources
- media articles and programs
- library resources

Procedure

1. (3A) In groups, use a search engine or the electronic catalogue at a library to research one alternative method of generating electricity.
2. With one group acting as a panel, evaluate the alternative methods of generating electrical energy presented by the various groups.
3. Include in the research:
   - a description of the method of generating electricity
   - a short history
   - most practical sites for installation
   - advantages of the method
   - disadvantages of the method
   - efficiency of the method
4. (8A) The group should make a presentation, including data, to show why their method of generating electricity is the one that should be chosen instead of other methods.
5. (7B) (6D) Graphs and charts should be used to show the efficiency of the method chosen.

Exploring

1. What is the primary source of electricity in your community at present?
2. Which method of generation of electricity from renewable resources is most practical in your community? Explain your answer.
3. Where could such a facility be located in your community? How would the facility affect the environment?
4. What impact would the other methods of alternative generation of electricity have on the environment in your community?
5. List some locations in Canada where the other methods of electricity production would be practical.

Challenge

Record the alternative methods of generating electricity presented in order of efficiency of use.

SKILLS HANDBOOK: (3A) Research Skills (8A) Reporting Your Work (7B) Constructing Graphs (6D) Creating Data Tables

Career Profile

Electrical Engineer

Like many young people in southern Ontario, Karen Cheung discovered science at the Ontario Science Centre. It was an exhibit about the electric light bulb that particularly fascinated her, as she realized just what a huge impact electricity has made on our lives.

> Following a career you love is a gift to yourself.

Science came easily to Cheung at school, where she particularly enjoyed the technical subjects. Knowing that employment prospects were good in the high-technology careers, she decided to major in Applied Science when she obtained a Bachelor's degree in Electrical Engineering at university. She followed this up with a master's degree in Applied Science, majoring in Communications.

Cheung then joined the legions of highly-qualified young graduates looking for work in the well-paid communications industry. She didn't have long to wait. She was soon hired by Nortel Networks as a software engineer, designing and developing software for use in communication applications such as phone switches and voice mail. Cheung finds her job challenging but rewarding. She especially enjoys digital signal processing (processing of digital images and signals) because it ties in well with her university training. She also gets satisfaction from writing code that works well, and that meets the needs of customers.

What are her plans for the future? She hopes to stay with Nortel Networks for some time, diversifying her skills by working on a variety of products, and assuming more responsibility.

Exploring

1. List at least 20 different occupations that, like Karen Cheung's, involve computer skills.
2. Not all software engineers have exactly the same academic background as Cheung. Research what other university degrees are recommended for similar careers.
3. Canada is a world leader in the telecommunications industry. Do an Internet search to find out what high-tech developments Canadian companies have made recently.

11.11 Explore an Issue

Bridging the Energy Gap

One fact is certain in Ontario. We are going to need to generate increasing amounts of electrical energy far into the foreseeable future. Our population and our economy are growing, which means that we will need more electricity. In this chapter, you have learned about energy resources currently being used to generate electrical energy. As our need for electrical energy grows, we are faced with a difficult choice. What energy resources should we use to provide the extra electrical energy? There are two basic options: we can build new generating stations to produce electricity using the three major energy resources we presently use, or we can try to use alternative energy sources.

Today's Energy Sources

Most of our electrical energy is presently produced from the two kinds of nonrenewable resources—fossil fuels and nuclear fuel—and one renewable resource—water operating hydroelectric generating stations. It is not likely that we can provide sufficient additional energy by using new hydroelectric resources because most of the hydroelectric sites that can produce large amounts of electricity are already being used. So, which of the two nonrenewable energy resources would be preferable for new generating capacity in the near future?

Both options have their problems. Fossil fuels are a finite resource and cause environmental problems both during mining and burning. Nuclear fuels are also a finite resource, and their use requires continuous careful maintenance. Furthermore, we have not yet found a satisfactory way of disposing of the spent fuel rods from the nuclear reactors and the waste materials at the mines where the uranium is produced.

Renewable Energy Sources

Several renewable energy sources—thermal, photoelectric, wind, biomass, and fuel cells—could perhaps be used to produce reasonably large amounts of electrical energy in Ontario. Geothermal and solar thermal energy sources are not practical alternatives at present. Photoelectric, wind, and biomass energy sources could be used to generate significant amounts of electrical energy, but the relative cost of producing electricity with each of these alternatives is currently too high for them to be economically viable (**Table 1**). For example, producing electricity with photoelectric cells is 22 times more expensive than hydroelectricity.

None of the renewable energy sources can currently be manufactured and operated cheaply enough to make them a viable alternative in the foreseeable future.

The logical conclusion, then, is that we will have to build new generating stations that use the same nonrenewable energy resources as our existing generating stations.

Table 1 Relative Cost of Energy Sources

Energy Source	Relative Cost (compared with hydroelectric)
hydroelectric	1
fossil fuels	2 – 5
nuclear fuel	2 – 5
geothermal energy	4 – 5
wind	4 – 5
biomass	5 – 7
photoelectric cells	22

Issue

Fossil Fuels or Nuclear Power? 8B

If we have to use nonrenewable energy resources, which is the best choice?

1. In small groups, research the issue using the Internet, your library, and any other sources available. 3A
2. Try to classify the information you obtain into scientific, technological, and societal categories wherever possible. 3B
3. Identify all the factors (short term and long term) related to the issue, and determine the position of your group. Consider the viewpoints of other people who would be affected by the consequences of your group's conclusion if it were carried out.
4. Write a one-page position paper, clearly stating your group's opinion and the reasons for it. Your group should also state any major problems related to the group's position.

Challenge

How will you incorporate your group's opinion and reasons into your information on energy consumption?

Chapter 11 Review

Key Expectations

Throughout the chapter, you have had opportunities to do the following things:

- Describe the relationship among electrical energy, electrical power, voltage drop, current, and time interval, and determine energy and power using the formula $E = P\Delta t$. (11.1, 11.2, 11.3, 11.4)
- Compare methods of producing electrical energy, including their advantages and disadvantages. (11.5, 11.6, 11.7, 11.8, 11.9, 11.10, 11.11)
- Describe and analyze electric circuits, and measure voltage drop and current values related to circuits. (11.1, 11.3, 11.7)
- Use safety procedures when conducting investigations. (11.1, 11.7)
- Investigate circuits, and organize, record, analyze, and communicate results. (11.1, 11.3, 11.7)
- Formulate and research questions related to electrical energy (and power) and communicate results. (11.3, 11.5, 11.6, 11.8, 11.9, 11.10, 11.11)
- Describe practical applications of current electricity. (11.6, 11.8)
- Explore careers requiring an understanding of electricity. (Career Profile)

KEY TERMS

anode
cathode
efficiency
electrical energy
electrical power
energy
fuel cell
joules
kilowatt
kilowatt hour
lead-acid cell
nonrenewable energy resources
photoelectric cell
rated capacity
renewable energy resources
substainability
watt
watt hour

Reflecting

- "Electrical energy is often called the 'in-between' form of energy because we produce it from energy sources such as fossil fuels or moving water, and then convert it into the forms of energy we need." Reflect on this idea. How does it connect with what you've done in this chapter? (To review, check the sections indicated.)
- Revise your answers to the questions raised in Getting Started. How has your thinking changed?
- What new questions do you have? How will you answer them?

Understanding Concepts

1. Make a concept map to summarize the material that you have studied in this chapter. Start with the word "energy."
2. Identify two devices that produce electrical energy from
   (a) sound energy
   (b) chemical energy
   (c) radiant energy
3. Identify three devices that use magnetic strips or magnetic particles to produce electrical energy.
4. Why are rechargeable cells called "secondary" cells?
5. Why are batteries made of nickel hydride preferred to lead-acid batteries?
6. List some of the energy sources that could be used to provide a source of hydrogen to operate a fuel cell. What is the other substance required to operate a fuel cell, and how is it obtained?
7. (a) Describe how a fuel cell operates.
   (b) What substances are produced as byproducts as a result of the operation of the fuel cell?
   (c) What impact do these byproducts have on the environment?

8. Why is such a high proportion of the electrical energy used in Ontario produced from nonrenewable energy resources?

9. What alternatives for producing electrical energy are currently available for small isolated communities?

10. Suggest reasons why most of the original energy in the fuel is wasted in the production of electrical energy.

11. What two factors contribute to energy losses in the transmission of electrical energy?

12. What is the factor in the equation for electrical energy that usually determines whether it is more practical to use joules or watt hours as the unit of energy for a particular calculation? Why?

13. A 6-V battery is being used to provide energy to two light bulbs connected in parallel. How will removing one of the light bulbs from its socket affect the time it will take for the battery to completely discharge? Explain why.

Applying Skills

14. (a) Calculate the energy released (in joules) from a 9-V battery that operated an alarm bell for 5 min. A current of 0.15 A flowed through the bell.
    (b) Calculate the energy released (in joules) from a 12-V car battery as it operated a starter motor. The current flowing through the starter motor was 350 A and the time the motor operated was 7.5 s.

15. Calculate the amount of energy used in each part of question 14 in units of watt hours instead of in joules.

16. (a) Calculate the power rating of a coffee maker that operates on a voltage of 120 V. A current of 5.7 A flows through the heater in the coffee maker.
    (b) Calculate the power rating of an electric kettle. A current of 12.5 A flows through the heating element and the operating voltage is 120 V.

17. Calculate the amount of energy used in each part of question 16 in kilowatts instead of in watts.

18. Design and draw a circuit using four dry cells and between one and four light bulbs. The cells and the bulbs can be connected in any desired circuit combination. Then design and draw two other circuits. Circuit 1 should discharge the four cells in one quarter of the discharge time of the original circuit. Circuit 2 should discharge the four cells in two times the discharge time of the original circuit. In each case explain why your circuits will discharge the cells in the required time. Think about the entire question before designing the first circuit.

19. Based on the information on solar panel power output listed on page 352, how many panels would be required to produce 11 kW·h of electrical energy per day if there were only three hours of direct sunlight available?

Making Connections

20. What form of energy is commonly used to alert you to the fact that the battery in a device is almost discharged? Why is this form of energy used?

21. (a) List three practical uses for photoelectric cells.
    (b) If photoelectric cells could be mass-produced at a low price, in what practical ways could they be used?

22. Which types of dry cells contain toxic materials? What would be the most responsible way to dispose of these cells? Why?

23. How can you determine the power rating of any electrical device used in Canada?

24. (a) What environmental problems can be caused by each of the various methods used to produce electrical energy?
    (b) How can these problems be eliminated or minimized?

25. (a) Predict which of the three ways of providing energy to drive cars will eventually become the most used. Explain why.
    (b) Why is the fuel cell considered to be preferable to the internal combustion engine for operating cars?

26. Suppose you had to choose whether to use a calculator operated by a battery or a set of photoelectric cells. What are the advantages and disadvantages of each type of calculator?

27. Compare using nonrenewable with renewable energy sources for producing electricity. What are the advantages and disadvantages of each?