Key Terms

electric circuit
voltaic cell
battery
electrode
electrolyte
dry cell
wet cell
primary cell
secondary cell
fuel cell

11.1 Cells and Batteries

As you know, electrons are involved in all static charges. Electrons are also involved in the circuits of electrical devices. An **electric circuit** is a closed path along which electrons that are powered by an energy source can flow. To function, a circuit requires a source of electrical energy, which is often a cell or a battery.

electric circuit a closed path along which electrons that are powered by an energy source can flow

Electric and Hybrid Vehicles

The first electric cars, such as the one shown in **Figure 11.1**, were built a century ago. Yet today, most of the vehicles on the road are powered by gasoline or diesel derived from fossil fuels. However, increasing fuel costs and concern for the environment have led to the development of hybrid and electric vehicles. In the future, electricity will play a key role in transportation. Electric vehicles are powered only by batteries, while hybrid vehicles use a combination of batteries and a fossil-fuel engine. In a hybrid vehicle, a small combustion engine burns fossil fuel, and an electric motor assists the combustion engine when the car is accelerating. This helps to reduce the need for fossil fuels.

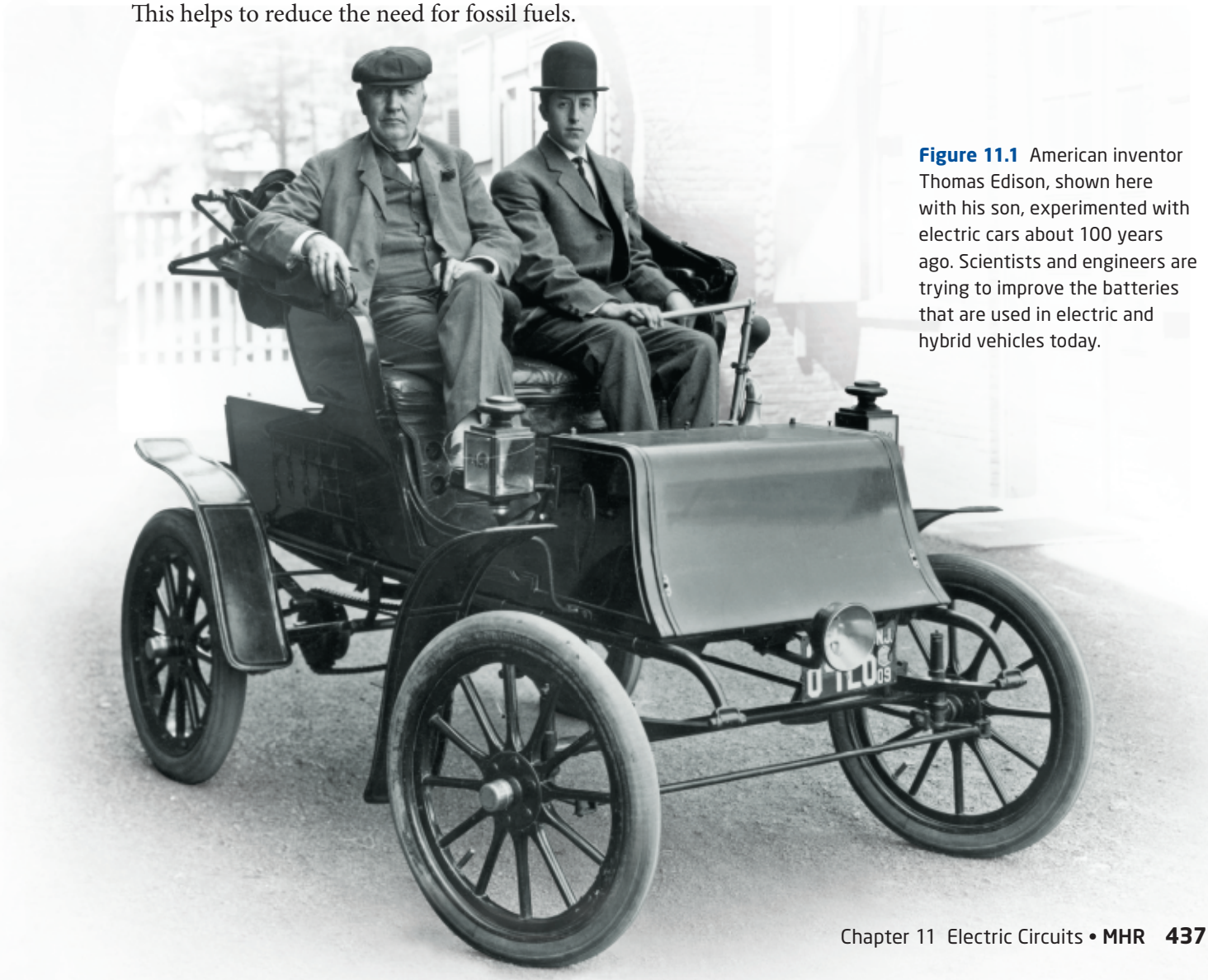


Figure 11.1 American inventor Thomas Edison, shown here with his son, experimented with electric cars about 100 years ago. Scientists and engineers are trying to improve the batteries that are used in electric and hybrid vehicles today.

Figure 11.2 When Volta invented this "pile," it had no practical uses.

Voltaic Cells

Most of the batteries that are used today are similar in principle to the battery constructed by Alessandro Volta, an Italian physicist, around 1800. He stacked alternating discs made of silver and zinc, separated by a piece of cloth soaked in salt water. Volta invented the first battery, which became known as a Voltaic "pile," shown in **Figure 11.2**.

From Cells to Batteries

The AA or D "battery" that you insert into a flashlight or portable radio is actually a **voltaic cell** (also called a cell). It generates an electric current by chemical reactions that involve two different metals or metal compounds separated by a conducting solution. A **battery** is a connection of two or more cells. You make a battery when you place two or more cells in a flashlight.

In a voltaic cell or battery, the two metal terminals are called **electrodes**. The electrodes must be made of different metals, with different abilities to hold on to electrons. The electrodes are immersed in a conducting solution or paste, called an **electrolyte**. You may have seen a "lemon clock," shown in **Figure 11.3A**, which has these features.

In a voltaic cell, chemical reactions take place at the surface of each electrode that is in contact with the electrolyte. The chemical reactions depend on the metals that are used, but the operation of every cell involves the movement of electrons and ions. **Figure 11.3B** shows what happens in a lemon cell that has aluminum and copper electrodes. The aluminum atoms give up three electrons, forming Al^{3+} ions. The Al^{3+} ions leave the aluminum electrode, enter the electrolyte solution, and move toward the copper electrode. As this happens, the strip of aluminum slowly disintegrates. The disintegration of an electrode is one factor that can limit the life of a cell. The electrons that are released by the aluminum atoms move through the connecting wires to the copper electrode.

voltaic cell a source of energy that generates an electric current by chemical reactions involving two different metals or metal compounds separated by a solution that is a conductor

battery a connection of two or more cells

electrode one of two metal terminals in a cell or battery

electrolyte a solution or paste that conducts charge

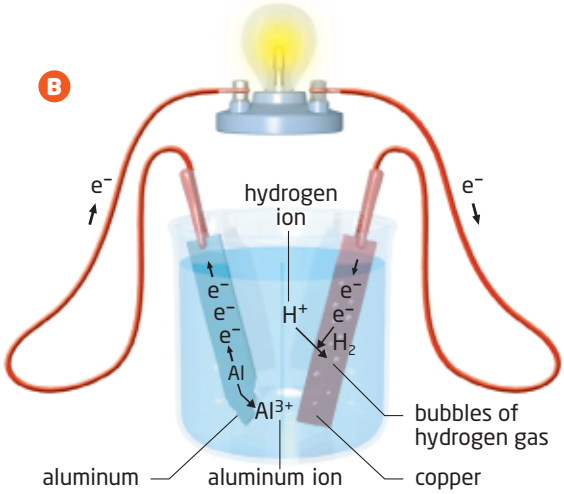


Figure 11.3 **A** The strips inserted in the lemon are made of different metals and function as electrodes. The lemon juice is the electrolyte. **B** In a cell, electrons flow from one electrode, through connecting wires, to the other electrode. The electrode that loses electrons forms positive ions, and these ions enter the electrolyte. At the other electrode, electrons combine with ions in the electrolyte.

Types of Cells

Because a battery is made up of cells that are connected together, batteries and cells are classified in the same way. One way they are classified is based on the electrolyte they contain: either dry or wet.

Suggested Investigation
Inquiry Investigation 11-A, Constructing and Comparing Voltaic Cells, on page 472

Dry Cells

Most of the cells you use are classified as dry cells. A **dry cell** contains an electrolyte that is a paste. A German scientist named Carl Gassner invented the first practical dry cell in 1887. Gassner's cell used zinc and carbon as electrodes. The electrolyte was made from a paste of plaster of Paris and a chemical called ammonium chloride. The inexpensive zinc-carbon cell in common use today, shown in **Figure 11.4A**, has changed little since Gassner's invention. The first major advance in dry cells came in 1959, with the alkaline cell, shown in **Figure 11.4B**. Alkaline cells are more expensive than zinc-carbon cells, but they have the advantage of lasting much longer. "Button" cells are either silver-oxide cells or zinc-air cells, shown in **Figures 11.4C** and **11.4D**.

dry cell a cell that contains an electrolyte that is a paste

Sense of Value
Today's alkaline batteries last 40 times longer than the first 1959 model.

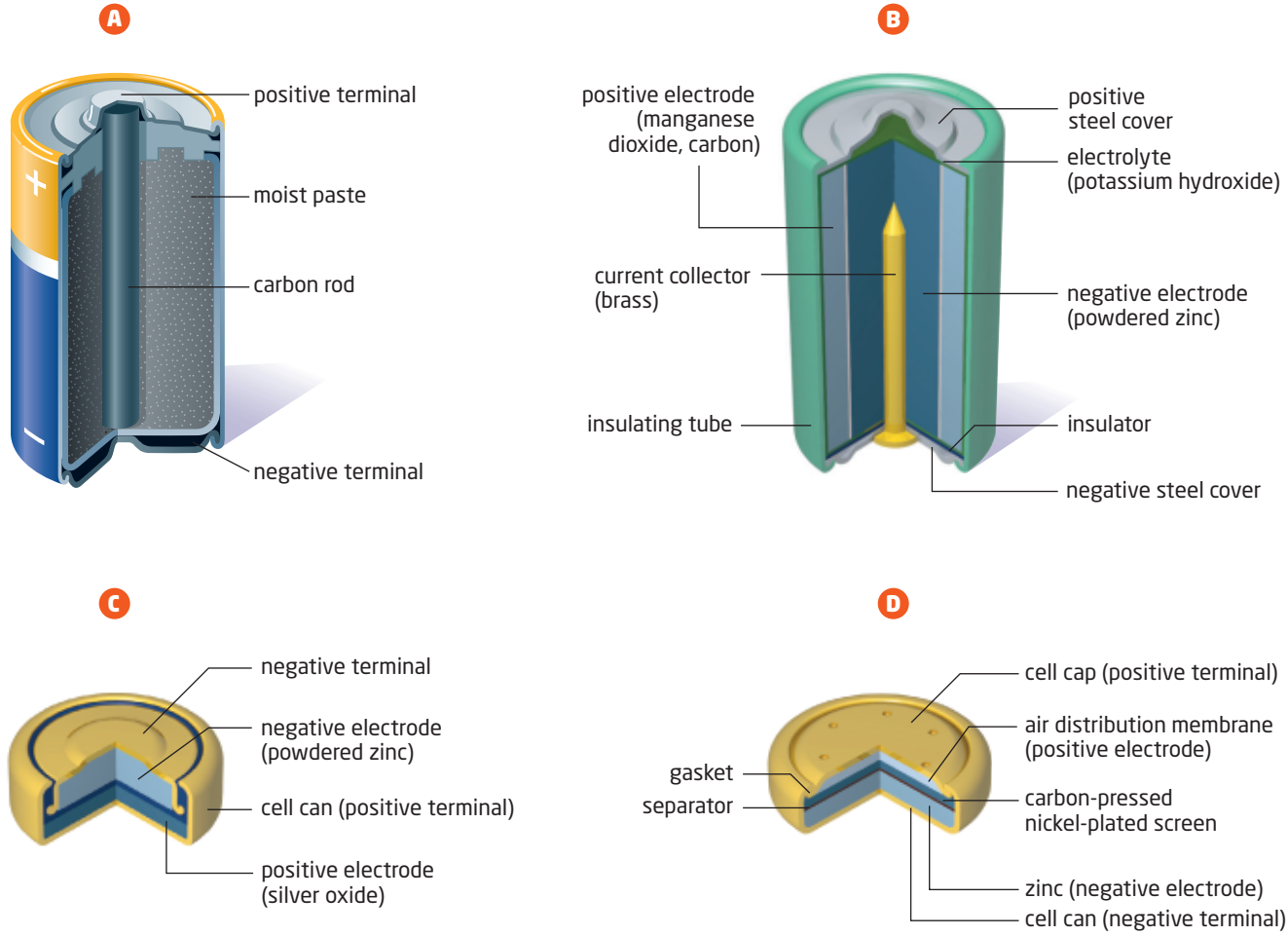


Figure 11.4 Different types of primary cells are used in calculators, hearing aids, computers, and toothbrushes. Four types of dry cells are shown: **A** a zinc-carbon cell, also called a D cell, **B** an alkaline cell, **C** a silver-oxide cell, and **D** a zinc-air cell.

wet cell a cell that contains a liquid electrolyte

primary cell a cell that can be used only once

secondary cell a cell that can be recharged

Study Toolkit

Comparing and Contrasting A graphic organizer such as a Venn diagram can help you to compare and contrast primary cells and secondary cells.

Wet Cells

A **wet cell** contains a liquid electrolyte. Volta's pile was a wet cell because the electrolyte was a salt solution. Most wet cells use a solution of sulfuric acid as an electrolyte, because sulfuric acid is an inexpensive, strong acid. However, sulfuric acid is a corrosive liquid, and contact with the skin may cause injury.

Primary and Secondary Cells

A second way that cells are classified depends on whether they can be recharged. A **primary cell** can be used only once, and then it is discarded. All the cells that are shown in **Figure 11.4** are primary cells. A **secondary cell** can be recharged many times. In a secondary cell, an electric current is passed in the opposite direction through the cell from another source. The charging current reverses the chemical reactions that take place in the cell, essentially restoring the cell to full capacity. The lead-acid battery that is used in trucks, automobiles, motorcycles, and wheelchairs is a secondary wet cell. **Figure 11.5** shows this and other common secondary cells.

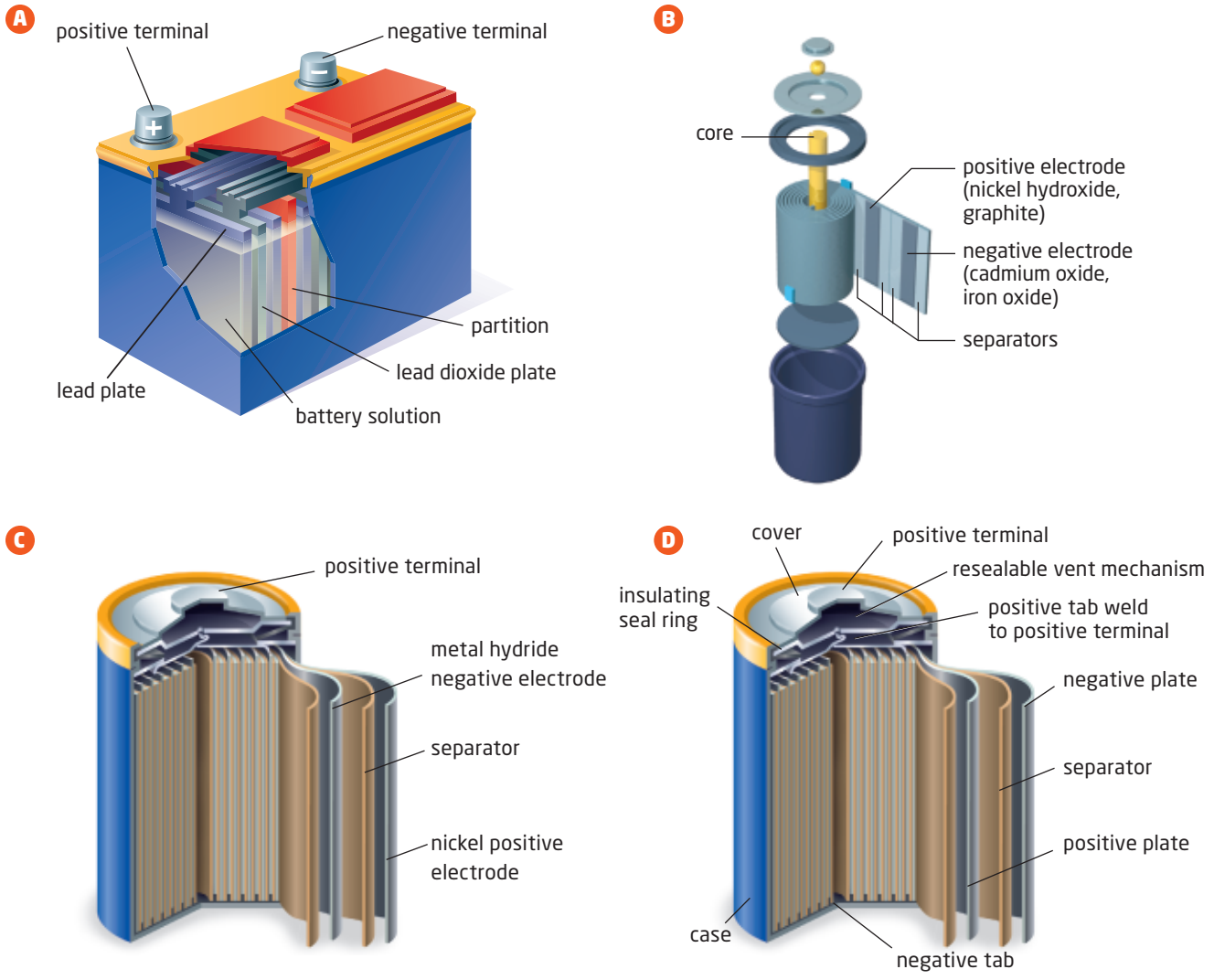


Figure 11.5 These are four examples of secondary cells: **A** a lead-acid battery, **B** a nickel-cadmium cell, **C** a nickel-metal hydride cell, and **D** a lithium-ion cell.

Table 11.1 Cells and Batteries in Common Use

Name	Primary/ Secondary	Dry/Wet	Typical Uses	Pros	Cons
Zinc-carbon	Primary	Dry	Flashlights, small radios, music players	Is inexpensive	Gives poor performance at low temperature
Alkaline	Primary	Dry	Flashlights, small radios, music players	Lasts longer than zinc-carbon cells	Is more expensive than zinc-carbon cells
Silver-oxide	Primary	Dry	Calculators, watches, hearing aids, pagers	Is small and long-lasting	Is relatively expensive
Zinc-air	Primary	Dry	Hearing aids, pagers	Has a long shelf life if sealed	Requires oxygen from the air
Lead acid	Secondary	Wet	Cars, trucks, motorcycles, snowmobiles	Delivers high current; is inexpensive	Is heavy; contains a corrosive electrolyte; has a short storage life
Nickel-cadmium	Secondary	Dry	Portable power tools, laptop computers, shavers, toothbrushes	Can be recharged 500 to 700 times	Is an environmental hazard because of the cadmium
Nickel-metal hydride	Secondary	Dry	Portable power tools, laptop computers, shavers, toothbrushes	Can be recharged 300 to 400 times; is good for high-demand applications, such as cameras and power tools	Is relatively expensive
Lithium-ion	Secondary	Dry	Cellphones, laptop computers	Can be recharged 300 to 400 times; has an excellent shelf life; is good at high and low temperatures	Is relatively expensive

Activity 11-2

Make a CELLection

There are many cells and batteries that can be used to provide electrical energy. For some applications, more than one type of cell can be used. What properties would you consider important if you were selecting a cell for each of the following applications?

Applications

- key holder with a light
- golf cart
- travel alarm clock
- camcorder
- portable drill
- child's singing teddy bear
- flashlight
- pacemaker
- snowblower
- engine starter
- scuba diver's light
- road-hazard warning light

Procedure

1. Design a table with four headings: Application, Properties of Cells That Could Be Used, Recommended Cell, and Reasons for Recommendation.
2. Research the meanings of these properties: storage, capacity, recharge life.
3. Using the information in **Table 11.1** and other sources, recommend a cell for each application. Consider the properties you listed in Procedure step 2, as well as cost and environmental impact.

Questions

1. Which cells have the least impact on the environment? Explain your reasoning.
2. Did you recommend primary cells or secondary cells more often? Explain your choices.
3. Think about the portable devices you use and the cells that provide them with electrical energy. Would you change the type of cell you use for any of these devices? Explain your reasoning.

Fuel Cells

fuel cell a cell that generates electricity through the chemical reactions of fuel that is stored outside the cell

A **fuel cell** generates electricity through the chemical reactions of fuel that is stored outside the cell. A hydrogen fuel cell combines hydrogen that is stored in a tank or cartridge with oxygen from the air. The only by-products of the reaction are heat and water. Fuel cells were originally developed for the U.S. space program, to help keep astronauts warm and provide them with drinking water. Fuel cells are capable of providing the energy for automobiles, buses, and small devices such as cellphones.

Figure 11.6 Fuel cell cars and buses are quiet and non-polluting. The fuel cells are expensive, however, and require hydrogen gas, which must be produced from other sources.

STSE Case Study

Electric Avenue

As gasoline gets more costly, in terms of both price and environmental effects, consumers are looking for alternatives to gasoline-burning vehicles. Electric cars, which make more efficient use of energy, are one answer. Because electric engines run only on batteries, they emit no greenhouse gases while running. The generation of the electricity they use, however, does produce some carbon dioxide emissions.

Toronto-based ZENN Motor Company, whose name stands for "zero emission, no noise," produces fully electric cars. The ZENN car is manufactured in St. Jérôme, Québec. It is a hatchback low-speed vehicle (LSV), powered by six heavy-duty lead-acid batteries. Its top speed is 40 km/h, it can hold two people, and it costs $16 900. Its range (the distance it can travel on fully charged batteries) is 50 to 80 km.

Advantages of Electric Cars

As well as the advantage of emitting no greenhouse gases, electric cars have several other advantages over gasoline-burning vehicles. To charge an electric car, it is plugged into a normal wall socket. A ZENN car is 80 percent charged in four hours and completely charged in eight hours. Depending on how much an electric car is used, its battery pack will last three to five years. When an electric car is not moving, such as in a traffic jam, it does not use its stored power or produce any exhaust.

The ZENN electric car is a low-speed vehicle that is powered only by batteries. It is manufactured in Canada. Québec and British Columbia were the first provinces to allow it on city streets.

Fuel Cell Vehicles

Ballard Power Systems, based in Burnaby, British Columbia, develops and manufactures hydrogen fuel cells. Ballard is cooperating with other companies to work on a new fuel cell for use in cars. Fuel cells are also being developed for use in public transportation, as shown in **Figure 11.6**.

Go to **scienceontario** to find out more

Learning Check

1. Sketch and label the main parts of a voltaic cell.
2. Refer to **Table 11.1** on page 441. Give an example of
   a. a dry primary cell **b.** a wet secondary cell
3. Is a fuel cell a primary cell or a secondary cell? Explain.
4. A soil tester for plants uses a meter to display moisture content when the end of a probe is placed in the soil. No batteries are needed. How does the soil tester work?

Relative Energy Consumption and Costs

A gasoline-burning car wastes fuel and releases carbon dioxide when it is stuck in traffic because its engine is still running. On average, only 12 percent of the energy that is produced by burning gasoline goes toward making a car move. An electric engine that is charged by the power generated at an oil-burning generating plant converts twice as much energy to making a car move. As well, because an electric car has fewer moving parts, it needs less maintenance. Considering all the costs, a ZENN car costs less than two cents per kilometre to operate. A conventional car can cost 10 times as much per kilometre.

Disadvantages of Electric Cars

One concern with electric cars is that charging them increases our electricity needs and may have a significant effect on the environment if the energy source is fossil fuels. If the power that is used to charge the batteries, however, comes from renewable sources, such as wind or solar energy, an electric car is a very "green" method of transportation.

Another concern with electric cars is their limited range. Once the batteries are out of power, completely recharging them takes several hours. More high-tech batteries exist, but their cost is much greater. The range of electric cars is not a major concern for short distances, however, and electric cars are not intended for use on highways.

Getting Greener

Electric cars are an important step toward reducing the use of the internal combustion engine and achieving more efficient and environmentally friendly methods of transportation.

How can we meet our transportation needs in an environmentally friendly way?

- Drive an electric car, especially for short distances.
- Carpool to school or work.
- Combine errands and other trips to reduce the amount driven.
- Use public transportation.
- Get some exercise–walk or ride a bicycle.

Your Turn

1. Suppose your family is discussing what kind of car to purchase. What would you tell your parents about the pros and cons of an electric vehicle?
2. Why does the source of power that is used to charge an electric vehicle make a difference to its energy efficiency and the amount of carbon compounds it releases? What could government and power utilities do to make electric cars an even greener method of transportation in your area?
3. Write a persuasive letter to your MPP explaining why you think low-speed electric cars should or should not be allowed on Ontario roads.

Solar Cells

solar cell a cell that converts sunlight into electrical energy

The Sun will continue to supply energy for billions of years. Earth receives more energy from the Sun in one hour than all the energy consumed by humans in a year. How can the Sun's energy be harnessed and stored for use at night and on cloudy days, at a reasonable cost?

A **solar cell** converts sunlight into electrical energy. For example, when sunlight strikes a semiconductor, such as silicon, electrons are knocked loose from the atoms. A few small solar cells can provide enough energy for a calculator or an ornamental garden light, and large solar panels can operate a communications satellite. For several years, the Ontario government has been encouraging renewable energy projects through a program called the Renewable Energy Standard Offer Program (RESOP). This program has been modelled after a program in Germany. An example of a solar farm is shown in **Figure 11.7**.

Figure 11.7 These solar panels and tower are part of the Solar 2 farm in California.

Making a Difference

Corey Centen and Nilesh Patel were McMaster University engineering students when they designed a technology that could save lives. The two were chatting one day about the CPR training they received in high school. They realized that they could not remember the proper CPR steps or how fast or hard they were supposed to compress a victim's chest. After reading studies, they discovered they were not alone: most people trained in CPR do not perform it effectively.

To solve this problem, Corey and Nilesh invented the CPRGlove™. The glove uses circuits, electrodes, and sensors to measure the speed of CPR, the depth of compressions, and heart rate. It gives the person wearing it a digital display of information about what they are doing wrong when they are performing CPR incorrectly.

Corey and Nilesh have started a company, Atreo Medical Inc., to market their glove. *Time* magazine named the glove one of the best health inventions in 2007.

What new technology could you invent to help solve a problem you have experienced?

Section 11.1 Review

Section Summary

- In a voltaic cell, chemical reactions involve two different metals or metal compounds (called electrodes), and a conducting solution or paste (called an electrolyte).
- A battery is a connection of two or more cells.
- A dry cell contains an electrolyte that is a paste, whereas a wet cell contains an electrolyte that is a liquid solution.
- A primary cell can be used only once, and then it is discarded, whereas a secondary cell can be recharged many times.
- A fuel cell generates electricity using chemical reactions of fuel stored outside the cell.
- A solar cell converts sunlight, a renewable energy source, into electrical energy.

Review Questions

A **1.** Compare the consequences to the environment of using an electric car and a hybrid car.

K/U **2.** Explain why the electrodes in a cell must be made from different materials (usually metals). See **Figure 11.3**.

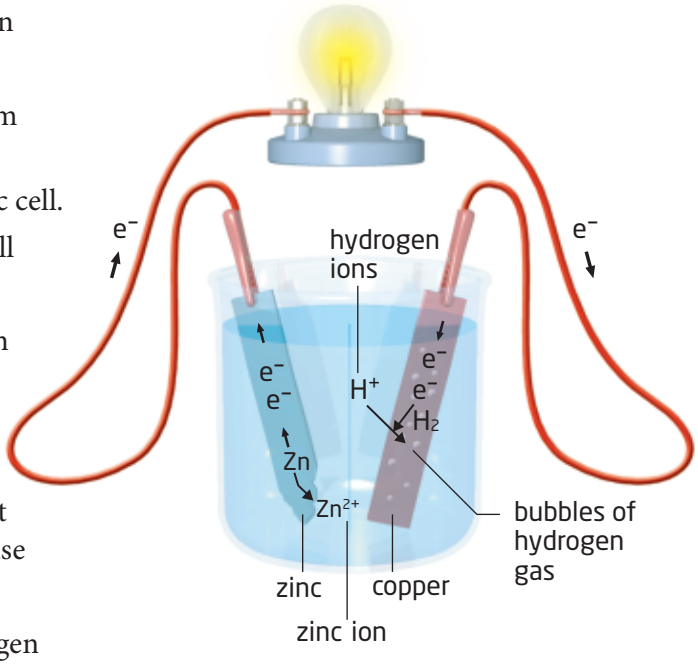
K/U **3.** List two ways in which batteries are classified.

K/U **4.** What is an electrolyte? Explain the function of an electrolyte in a cell.

T/I **5.** Part of a voltaic cell is shown in the diagram on the right.

a. Describe the role of electrons in a voltaic cell.

b. Which electrode will lose mass as the cell operates? Explain your answer.



T/I **6.** A flashlight can be powered by zinc-carbon cells, alkaline cells, or rechargeable cells. Design an experiment to find out which type of cell lasts longest.

C **7.** Write a pamphlet advising consumers what cell is best to use in a flashlight, based on use and cost.

T/I **8.** What would need to be done before hydrogen fuel cells can be practical for general use in automobiles?