PART 3 Compounds, Elements, and Chemical Reactions

LESSON **20**

Breaking Down a Compound

The surface of the Earth is four-fifths water. What is water made from?

INTRODUCTION

In the first part of this module, you looked at the characteristic properties of pure substances. In the second part, you investigated how these properties can differ from the properties of mixtures. In this part, you will focus on two groups of pure substances known as elements and compounds. In this lesson, you will examine the composition of the pure substance you have encountered most often during the course of this module—water. You know that water has several characteristic properties that can identify it as a single substance rather than a mixture. These properties include its appearance, density, melting and boiling points, and ability to dissolve a wide range of solutes. You will investigate what happens to water when electricity is passed through it. Sometimes, passing electricity through a liquid can give clues about the composition of the liquid. If water is a pure substance, why try to find out its composition? Do the inquiry and find out what happens!

OBJECTIVES FOR THIS LESSON

Conduct an experiment to determine what happens when electricity is passed through water.

Investigate some physical and chemical properties of gases.

Discuss the differences between compounds and elements.

Getting Started

1. Have you ever heard the terms “element” and “compound”? What do these terms mean? Without referring to a dictionary or your Student Guide, write definitions for each of these terms in your science notebook.

2. In your notebook, give two examples of an element and two examples of a compound.

3. Your teacher will lead a brainstorming session on what you think these words mean. You will look at these ideas again at the end of the lesson.

SAFETY TIPS

Wear safety goggles throughout this inquiry.

Tie back long hair.

MATERIALS FOR LESSON 20

For you

- 1 copy of Student Sheet 20.1: Electrolysis of Water
- 1 pair of safety goggles

For your group

- 1 plastic container
- 2 test tubes
- 1 electrode stand
- 1 jar of sodium sulfate
- 1 lab scoop
- 1 plastic spoon
- 1 wooden splint
- 2 6-V batteries (shared with another group)
- 1 insulated connector wire with alligator clips
- Access to water
- Access to a burner

Inquiry 20.1
Splitting Water

PROCEDURE

1. Your teacher will demonstrate the procedure for passing an electric current through water. After the demonstration, follow Steps 2 through 10 to set up your apparatus.

2. Place the electrode stand in the plastic container.

3. Make sure the leads hang over the side of the container.

4. Add water to the container so that the tips of the electrodes are covered by about 1 cm of water (see Figure 20.1).

5. Add two lab scoops of sodium sulfate to the water.

6. Stir the solution with the plastic spoon.

7. Submerge one of the test tubes in the container of sodium sulfate solution (see Figure 20.2).

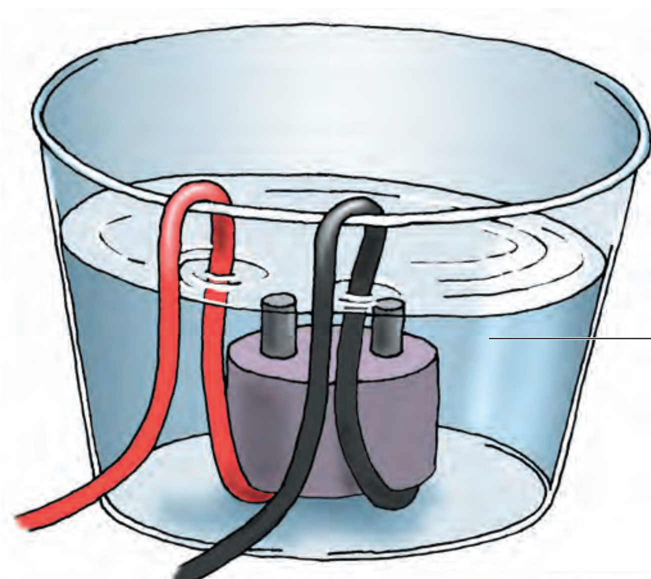

Figure 20.1 *Place the electrode stand in the plastic container and add water.*

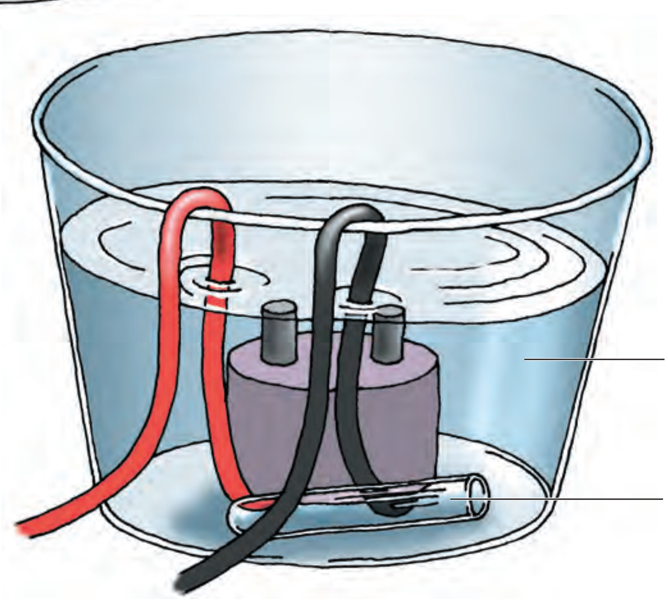

Figure 20.2 *Submerge the tube and make sure it is full of sodium sulfate solution.*

8. When the tube is full of solution, place your thumb or finger over its top. Making sure the open end of the tube is below the liquid, place the opening of the tube over one of the electrodes. The tube must still be full of liquid.

9. Repeat Steps 7 and 8 with the second test tube. (Do not worry if a few small bubbles of air get into the tubes.) Figure 20.3 shows what your apparatus should look like. Wash your hands after handling the tubes.

10. Clip the connector wires onto the batteries. Clip the red connector wire to the positive terminal of one battery and the black connector wire to the negative terminal of the other battery. Make sure the two remaining terminals on the batteries are connected. (See Figure 20.4.) You will be sharing the two batteries with another group. Figure 20.5 shows how to set up the apparatus for both groups.

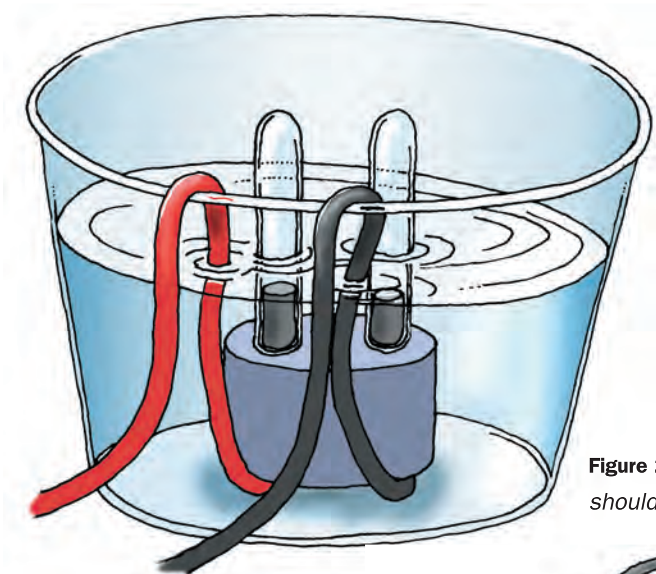

Figure 20.3 *At this stage, your apparatus should look like this.*

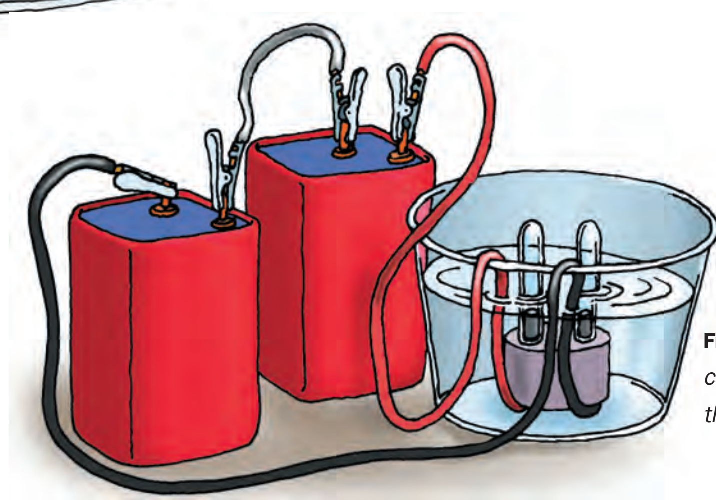

Figure 20.4 *Clip the connector wires onto the batteries as shown.*

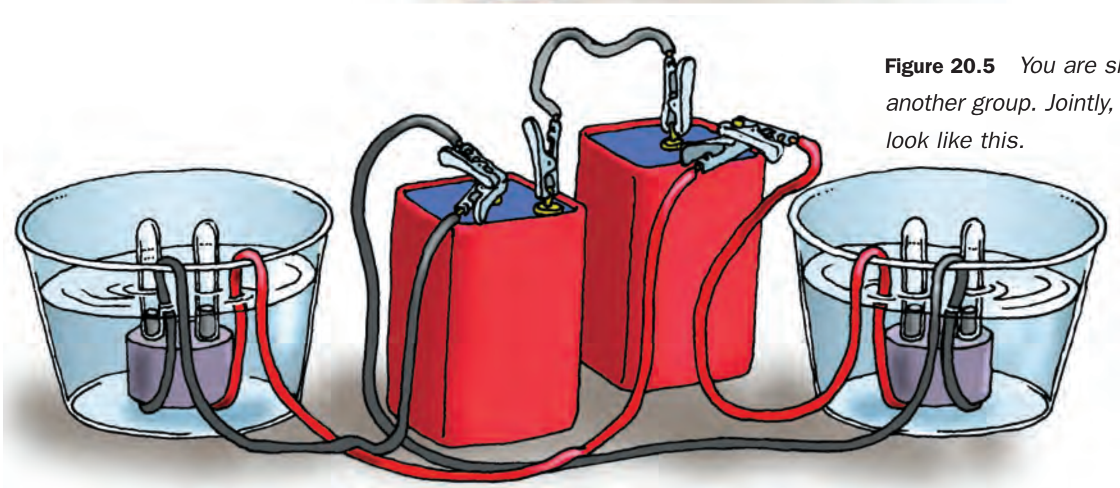

Figure 20.5 *You are sharing batteries with another group. Jointly, your apparatus should look like this.*

11. If you have assembled your apparatus correctly, you should soon start to see something happening near the electrodes. What do you observe happening at each of the electrodes? Write your answers on the student sheet.

12. What do you observe about the volumes of the two substances collected in the tubes? Write your answer on the student sheet.

13. Your teacher will conduct a class discussion about your observations. Be prepared to participate.

14. You *(or your teacher, if you do not have time to collect enough of each gas)* can test the gases produced in each test tube by putting a burning splint into each tube. If your group is conducting this test, follow these instructions:

A. Disconnect the battery from your apparatus.

B. Have one member of your group ignite the splint so it is burning.

C. Have another group member carefully remove a gas-filled tube from the negative electrode. It is alright if a little solution in the tube empties back into the plastic container. Hold the tube with the open end down (inverted.)

D. With the open end down, tilt the test tube at a 45° angle and quickly put the lit end of the splint into the mouth of the test tube. Look *and listen!*

E. Record your results under "Tube 1" in Table 1 on Student Sheet 20.1.

F. Refill the test tube with sodium sulfate solution, reconnect the battery, and continue to collect gas.

G. When the test tube over the positive electrode is filled with gas, perform the same test.

H. Record the results under "Tube 2" in Table 1.

15. When the tube over the negative electrode has refilled with gas, perform the following test:

A. Have one member of your group remove the test tube from the negative electrode, keeping it sealed with his or her thumb or finger. Hold the tube in an upright position (open end up.)

B. Another member of the group should ignite the splint.

C. Blow out the splint and then quickly put the glowing end into the tube of gas.

D. Carefully observe what happens and record the results under "Tube 3" in Table 1.

E. Repeat the test with a tube full of gas from the positive electrode.

F. Record your results under "Tube 4" in Table 1.

16. Hydrogen gas burns with a squeaky pop, and oxygen relights a glowing splint (or makes it glow much brighter). Based on your experimental evidence, what is inside each tube? Write your answers under Steps 4a and b on the student sheet.

17. Read "The Electrolysis of Water," on page 175.

THE ELECTROLYSIS OF WATER

In Inquiry 20.1, electricity was used to split water into hydrogen and oxygen. This process is called electrolysis ("electro" refers to electricity and "lysis" means "to break apart"). To break down water through the process of electrolysis, electricity must be able to flow through the water and complete an electrical circuit.

Electricity does not flow easily through pure water because pure water is a poor conductor of electricity, making it difficult to complete an electrical circuit. Adding sodium sulfate to pure water helps the water conduct electricity, which makes it easier to complete an electrical circuit. The energy from the electric current causes a chemical reaction to take place. During the reaction, sodium sulfate does not produce any products that can be detected. All of the gases produced during the electrolysis of water come from the water.

REFLECTING ON WHAT YOU'VE DONE

1. Write the answers to the following questions on Student Sheet 20.1:

A. Which two gases make up water?

B. You know that water is a pure substance. You have found out that it is made from two gases. Both gases are also pure substances. However, these gases cannot be broken down into other substances. Pure substances that cannot be broken down into other substances are called elements. Pure substances that are made up from more than one element are called compounds. Do you think water is an element or a compound?

C. Unlike mixtures, pure substances that are compounds always have the same ratio of elements in them; in other words, they have fixed compositions or formulas. What is the ratio of hydrogen to oxygen in water?

D. Water is sometimes written as a formula, H_2O. What do you think this formula means?

2. Think about how the characteristic properties of water differ from the characteristic properties of hydrogen and oxygen. Read about some of them in the reader "Hydrogen and Oxygen," on pages 176–177. Your teacher will collect your ideas and compile them in a table. Copy this table in your notebook.

3. Review the definitions of the terms "element" and "compound" that you wrote at the beginning of the lesson. Discuss with your partner how your ideas have changed. Write your ideas in your notebook.

HYDROGEN AND OXYGEN

Water is a compound made up of two elements—hydrogen and oxygen. The characteristic properties of these elements are different from those of water. However, hydrogen and oxygen have some common properties. They are both colorless, odorless gases, and they both readily react with other elements—making them "reactive" elements. But in many ways they are very different from each other.

Hydrogen has the lowest density of all the elements. It is very reactive, which is one reason why it is present in only very small quantities in air. It reacts with oxygen. You reacted it with oxygen when it burned with a squeaky pop. What do you think was made in that chemical reaction?

It may come as a surprise to you to discover that hydrogen is the most common element in the universe. The sun and other stars are mainly hydrogen gas. Hydrogen is found in many compounds. For example, all acids contain hydrogen.

Oxygen reacts with other substances. Some of the properties of oxygen were discussed in the reader "Air Heads" (in Lesson 4). Oxygen is needed for burning to take place. Things burn well in oxygen, producing hotter flames. For example, what happened to the glowing splint when it was put into a tube of

Water is a compound formed when inflammable hydrogen reacts with oxygen. Here, it is being used to put out a fire. Like all compounds, the properties of water are very different from those of the elements from which it is composed.

almost pure oxygen? Some welding and metal-cutting equipment use flammable gases and pure oxygen to produce the high temperatures needed to melt metal.

Oxygen also reacts slowly with many substances. Many compounds containing oxygen are called oxides. You've already come across the two oxides that are gases—carbon dioxide and sulfur dioxide—but most oxides are solids. In fact, oxygen is the most common element in the Earth's crust, but most of it is combined with other elements to form minerals that make up rocks.

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When flammable gases such as acetylene are burned in pure oxygen, very high temperatures are produced. This oxyacetylene torch burns a mixture of acetylene gas and oxygen, which produces a flame hot enough to cut or weld steel.

Car Battery or Chemical Factory?

Have you ever wondered where the electricity in batteries comes from? How is it possible to store electricity? If you look inside a battery, you can't see electricity! Perhaps the inquiry on the electrolysis of water holds a clue to answering these questions.

In the experiment on the electrolysis of water, you used electrical energy to produce a chemical reaction—splitting the water into hydrogen and oxygen. A battery does the reverse: It uses a chemical reaction to produce an electric current. A battery stores energy as chemical energy. When a battery is connected to a complete electrical circuit, it releases its stored energy in the form of electricity.

A car battery is not part of a complete electrical circuit until a key is turned in the ignition. Once the key is turned, the electrical circuit is complete, causing a chemical reaction to take place in the car battery. Sulfuric acid and plates of lead metal and lead oxide react to form lead sulfate. During this process, electricity is produced.

Car batteries rarely die, because once the car is started, a generator attached to the engine continually recharges the battery. During

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Car batteries store energy. During a chemical reaction, this chemical energy is transformed into electrical energy.

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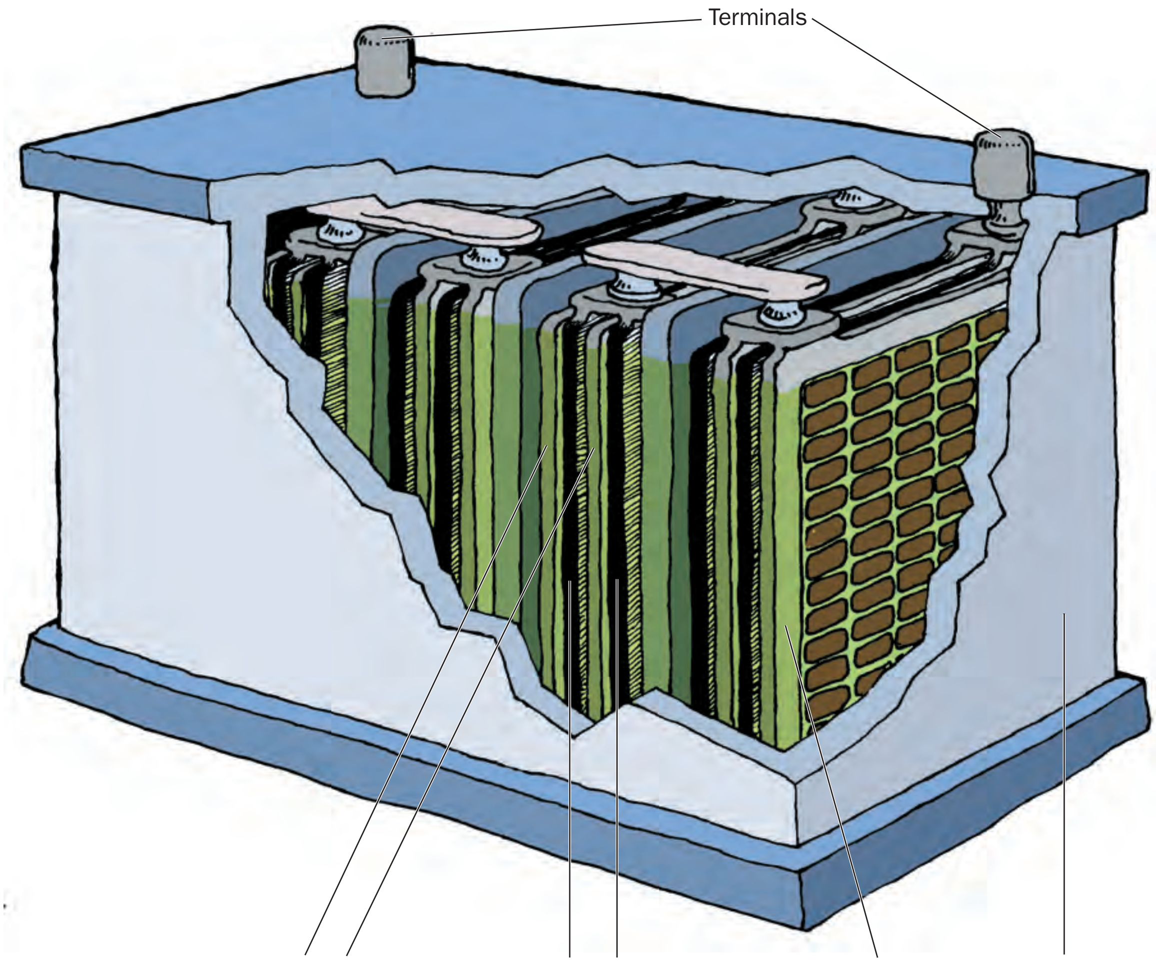
There are many other types of rechargeable batteries (including the one used in this cell phone). All of them release electrical energy through chemical reactions.

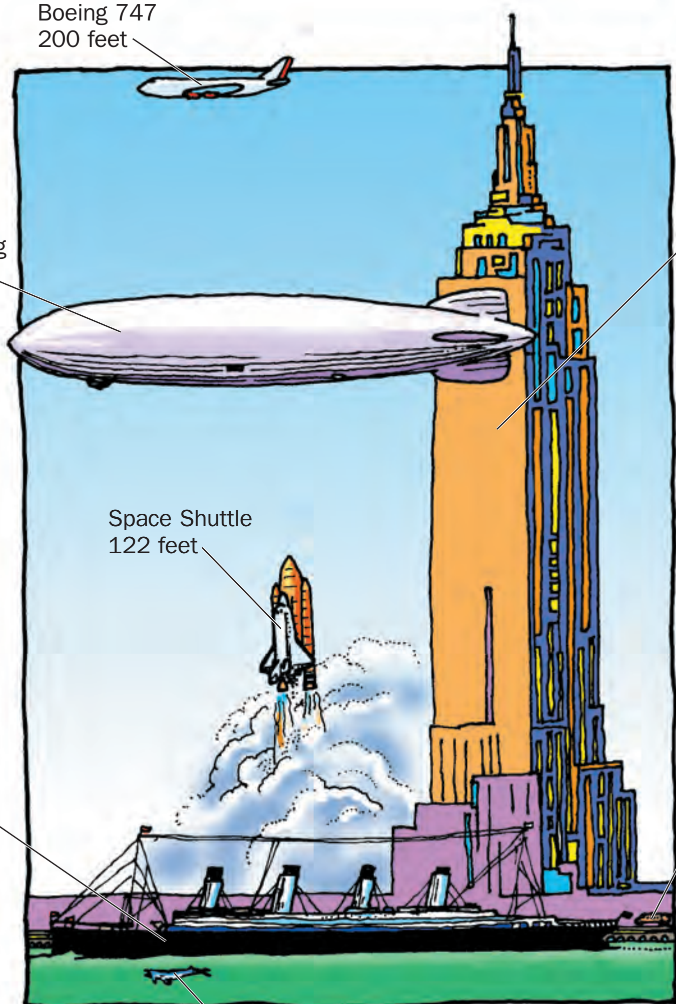


The inside of a car battery is like a chemical factory. Chemical energy is stored and then released as electrical energy. What are the reactants and products of this chemical reaction?

recharging, electricity flows through the battery in the opposite direction, reversing the chemical reaction. Car batteries, unlike the batteries used in flashlights and boom boxes, can be recharged thousands of times before they need to be replaced. □

The Properties of Hydrogen and the Death of an Airship

Date: Thursday
May 6, 1937
Time: 7:25 p.m.
Location: Lakehurst Air Station
New Jersey



The Hindenburg *was bigger than a jumbo jet and almost as long as the* Titanic.

As the 804-foot-long, hydrogen-filled airship, the *Hindenburg*, passed over Lakehurst Air Station, it turned to make its final approach. The crew opened ballast tanks to slow its descent, and water gushed from the bottom of the ship, soaking the mooring party below. Everyone at the station was watching the *Hindenburg* as this masterpiece of modern technology hovered 200 feet above the ground. Near the giant airship, some members of the press adjusted their cameras and sound recorders while others scribbled in their notebooks. In the parking lot, more photographers stood on the tops of cars, attempting to get a better view.

Inside the cabin of the *Hindenburg,* some of the passengers were looking down at the crowds below, searching for the faces of family and friends. They could see the landing crew preparing to catch the ropes dropped from the airship. Suddenly, a deep thump emanated from the stern of the airship. People on the ground began to scream, and the men waiting below the airship began to run. The sky lit up.

Inside the airship, all was chaos. In the officers' mess hall, Werner Franz, a 14-year-old cabin boy,

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The hydrogen-filled airship, Hindenburg*, flies over New York City. Why was hydrogen used to fill this airship?*

was clearing away plates. As he reached into a cupboard, he felt the whole ship jerk. Plates from the cupboard fell on top of him. He managed to get up and stumble out into the gangway. Everything seemed to be on fire. A huge wall of flames was coming straight at him.

What Werner didn't know was that during docking, the fabric surrounding the hydrogen envelope that kept the ship aloft had somehow ignited. Not only did the fabric burn like dry paper, it started an explosive chemical reaction between the hydrogen inside the envelope and the oxygen in the air. The German engineers who had designed the *Hindenburg* had chosen the wrong materials to make an airship. They had built a floating bomb!

Frantically, Werner scrambled away from the flames, toward the front of the airship. The ship lurched again, tilting backward toward the stern. Werner fell and began to slide into the fire. Gathering all his strength, he desperately began to crawl along the floor away from the fire. He could feel the heat through the soles of his shoes. The flames were licking at his legs.

CORBIS/BETTMANN-UPI

Just before docking, the Hindenburg *burst into flames.*

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The fire consumed the entire airship. What substance was formed in this chemical reaction?

NEW YORK TIMES PICTURES

The Hindenburg's *surviving officers and crew, including Werner Franz, who is standing in the middle at the front, found out firsthand about the dangers of some chemical reactions.*

Suddenly, a gush of water knocked Werner flat against the floor. One of the ship's water tanks had burst above him, temporarily extinguishing the nearby fire. But a few seconds later, the fire was back. Werner grabbed at a nearby hatch, kicked it open, and jumped. Winded, he lay on the ground. Screams were still coming from all around. Pulling himself to his feet, he began to run away from the flames. He saw the *Hindenburg's* captain running in the opposite direction, back to the ship. He was trying to save some of the passengers. Werner turned to run back to help him. As he did so, he was grabbed from behind by an American naval officer, who pulled him to safety.

Thirty-five passengers and crew and one person on the ground died in the flames and wreckage of the *Hindenburg*, as did the dreams of its designers and travel by airship. All of this happened because two elements (which form water!) reacted together to create a disaster. ☐

Extracting Aluminum

CORBIS/JAMES L. AMOS

This aluminum and gold baby rattle was made for Prince Louis Napoleon of France in 1856. At that time, aluminum, like gold, was considered a rare and valuable metal.

Precious Metal

No one knew about aluminum until 1825. That's when a Danish chemist first extracted pinhead-sized bits of aluminum from a mineral called alumina. But, extracting aluminum from alumina was very difficult, and for most of the 1800s, aluminum was rare and expensive. It was so valuable that kings and queens had fine tea sets and ornamental objects made of aluminum.

Common Metal

Even though aluminum was once considered very rare, it is the most common metal in

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In 1884, aluminum was even chosen for a place of honor at the very tip of the Washington Monument, because it was such a rare metal.

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Aluminum is an excellent material for use in lightweight sports equipment, such as this baseball bat. What other sports equipment is made from aluminum?

Earth's crust, making up 8 percent of Earth's crust. This aluminum is not found as pure aluminum metal but is combined with other elements in the form of aluminum compounds. Today, aluminum is used for everything from airplane frames to soda cans and baseball bats. It is shiny, strong, and lightweight. It doesn't rust and can be shaped and cast. It's even inexpensive enough to use for wrapping leftovers. But aluminum did not become economical until a young inventor working in his backyard lab came up with a low-cost way to extract it from alumina.

Early Start

An eager experimenter, Charles Martin Hall began work on aluminum in 1880. Just 20 years old, he was in his first year at Oberlin College in Ohio.

Backyard Inventor

Working in a woodshed behind his house, Hall set out to find a way to use electric current to get aluminum metal out of alumina, which contains aluminum and oxygen. The hard part was finding the right liquid in which

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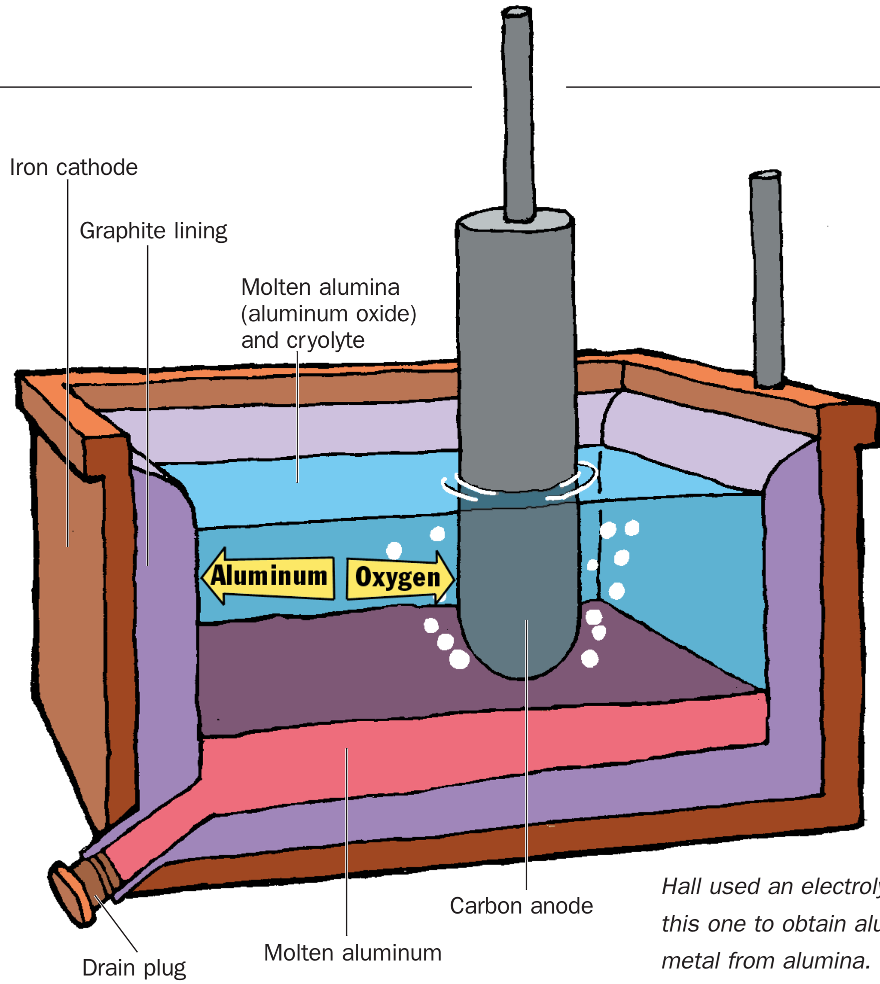
Charles Martin Hall developed a commercial process for producing aluminum.

to dissolve the mineral. Water wouldn't work. Passing electricity through a water solution of alumina only caused the water to break down into hydrogen and oxygen gas. Instead, Hall dissolved it in another mineral, called cryolite. This was tricky. First he had to melt the cryolite by heating it to more than 1000 °C. He used carbon electrodes to carry the current, because metal electrodes would have melted.



Hall used an electrolytic cell like this one to obtain aluminum metal from alumina.

Success!

On February 23, 1886, Hall had his first success. After running current through his setup for a few hours, he found several small globs of aluminum inside. He went on to start Alcoa Corporation, still one of the world's largest producers of aluminum. When Hall died in 1914, much of his fortune went to schools around the world. Oberlin College honors his generosity with this aluminum statue. ☐

The man and his metal: This statue of Charles Martin Hall is made from aluminum.

Hall's original samples of aluminum rest on top of his notes about the process he invented.