Chapter 10
Properties of Matter

Once the Statue of Liberty was as shiny as a new penny. Over many years, the air has affected the metal in the statue. Now, the statue is dull and green.

This chapter introduces the basic substances that make up everything on earth and throughout the universe. Then the chapter describes the different properties of these substances and explains how the substances change.

Chapter Objectives

1. Compare and contrast metallic elements with nonmetallic elements.
2. Distinguish between physical and chemical properties of matter.
3. Distinguish between physical and chemical changes.

10–1 The Elements

The ancient Greeks believed that all matter formed from four substances: fire, air, earth, and water. As you read about how we describe substances, you will discover answers to these questions:

a. What is an element?
b. How do we describe the elements?

Elements Are Basic Substances

An **element** is a substance that cannot be broken down into other substances by heat, light, or electricity. Elements are the basic substances that form matter. Gold, silver, mercury, and oxygen are elements. Carbon, shown below, is an element that occurs naturally in more than one form. Graphite is shown on the left, and diamond on the right. All living things contain carbon.

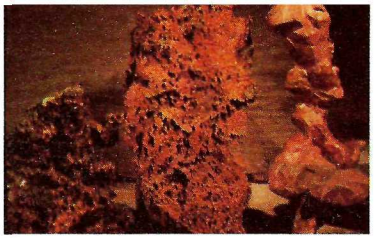
An element contains only one kind of atom. Copper is made of only copper atoms, and iron is made of only iron atoms. We define an **atom** as the smallest particle of an element with that element's chemical characteristics.

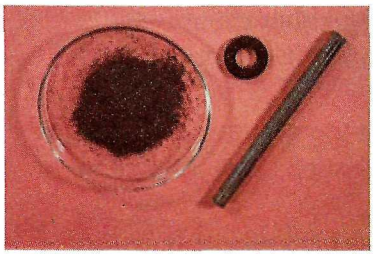
Everything in the world is made of a combination of atoms of the elements. For example, atoms of the elements hydrogen and oxygen make water. A combination of hydrogen, oxygen, and carbon atoms makes sugar.

Your body contains many of the elements, mainly oxygen, hydrogen, carbon, and nitrogen. Calcium is important in forming your bones and teeth. Zinc keeps your taste buds working properly. Copper helps your nerves function. Iron helps carry oxygen through your blood.


Gold

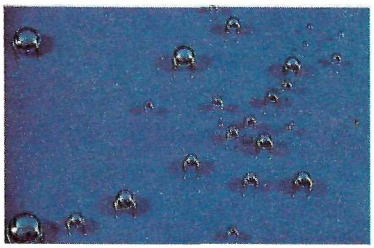

Silver


Copper


Iron


Tin


Lead


Mercury


Carbon


Sulfur

We know of 106 elements. Eighty-nine of them are found in nature. Scientists make the other elements in the laboratory by using high-energy machines.

Discovering all the elements took thousands of years. Ancient peoples worked with several of the elements, even though they did not know they were elements. The pictures above show these elements. Gold and silver were used in jewelry. Mercury was used as a medicine. Copper and tin were used for cooking utensils and were combined to make bronze for weapons. As time went by, people learned to use iron for making weapons.

For hundreds of years, only a few elements were known. During the time of the American Revolution, about twenty elements were known. But by the end of the Civil War, more than sixty elements had been discovered. In the century after the Civil War, the remaining naturally occurring elements were discovered. Today most scientists agree that all naturally occurring elements have been found.

Challenge!

Use an encyclopedia or another reference book to find out how and where the element helium was discovered.

Describing Elements

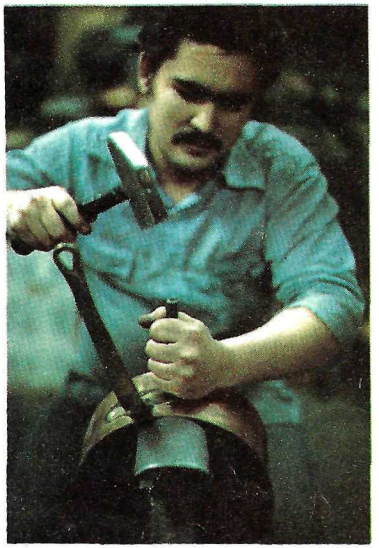
Scientists group elements according to their properties. The elements tin, lead, iron, and aluminum are examples of one group—the **metals.** Most elements are metals. Sulfur, carbon, and helium are examples of another group—the **nonmetals.** The pictures below illustrate the properties of metals.

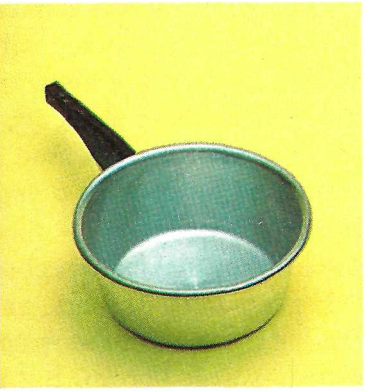
Most metals are solids at room temperature under ordinary pressure. Mercury is an exception. It is a liquid at room temperature.

Metals have a **luster** (lus′tər), which means how they shine. Manufacturers trim cars with the metal chromium because of its high luster. The ancient Romans polished silver to a high luster and used it as a mirror.

Metals conduct heat well. Some cooking utensils are made of copper, iron, or aluminum. A pot made of one of these elements heats quickly and distributes heat evenly.

Metals also conduct electricity. Even though silver and gold are the best conductors, electricians use copper in electrical wiring because of another property. Copper, platinum, and some other metals are **ductile** (duk′təl), which means that they can be drawn into a wire.





Some metals can also be hammered, rolled, or shaped without being broken. These metals are **malleable** (mal′ē ə bil). Copper, gold, and silver can be pounded into jewelry, and aluminum foil folds easily around your sandwich, because these elements are malleable.

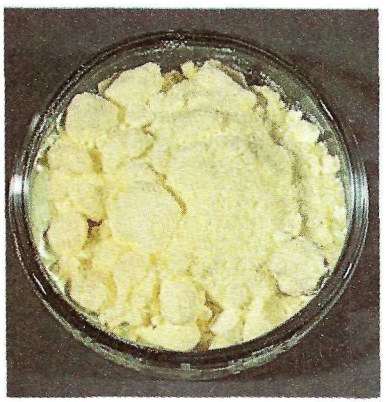
Fewer than two dozen elements are nonmetals. Some nonmetals are shown below. Chlorine, neon, hydrogen, and nitrogen are nonmetals. The properties of metals and nonmetals are opposites. The luster of nonmetals is low. They conduct heat and electricity poorly, and they are not ductile or malleable. At room temperature under ordinary pressure, most nonmetals are solids or gases. Sulfur, iodine, and phosphorus are solid nonmetals. Sulfur is a yellow crystal. Iodine is a dark purple crystal. Phosphorus, usually a soft, white solid, also occurs in a red form. The gaseous nonmetals include nitrogen, oxygen, and fluorine. Bromine is the only liquid nonmetal.

Some elements, such as arsenic and silicon, have properties of both metals and nonmetals. They are called **metalloids** (met′l oidz).

Review It

1. Define the word element.
2. How are metallic and nonmetallic elements different?

Sulfur



Iodine

Red phosphorus

10–2 Physical Properties and Changes

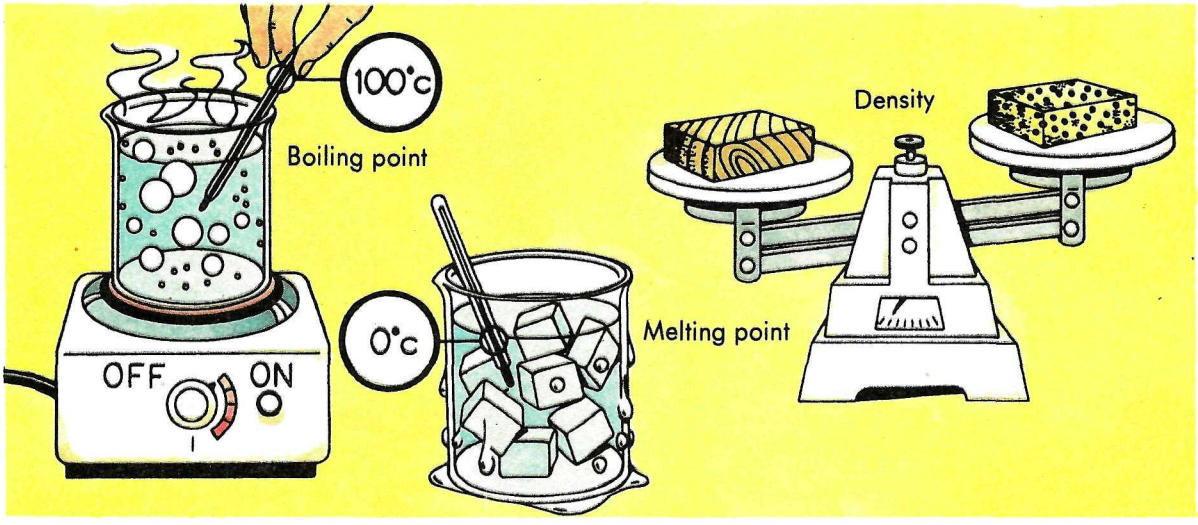
All matter can be described by its properties. Chewing gum, for example, could be described as thick, sticky, and stretchable. Answer these questions to begin learning how scientists describe matter:

a. What are the physical properties of matter?
b. What is a physical change?

Describing Physical Properties

A **physical property** is a property that can be observed without changing the identity of the substance. For example, as it melts, cheese changes its state, but it is still cheese. It still tastes and smells like cheese. If you cut a sheet of paper, you change the shape and appearance of the paper, but it is still paper. The pictures below show several physical properties. The properties of metals described earlier are physical properties.

Distinctive tastes or odors are physical properties of some substances. When blindfolded, you may not be able to taste the difference between two brands of bread, but you can taste the difference between bread and a lemon. Many substances have distinctive odors too. Rotten eggs, for example, get their smell from a substance in them that contains hydrogen and sulfur.

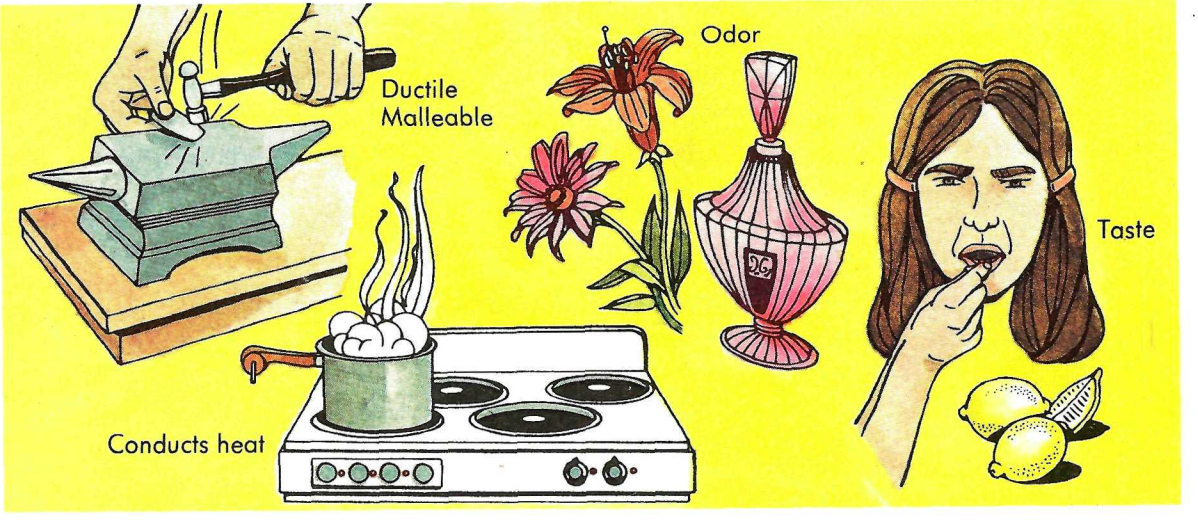


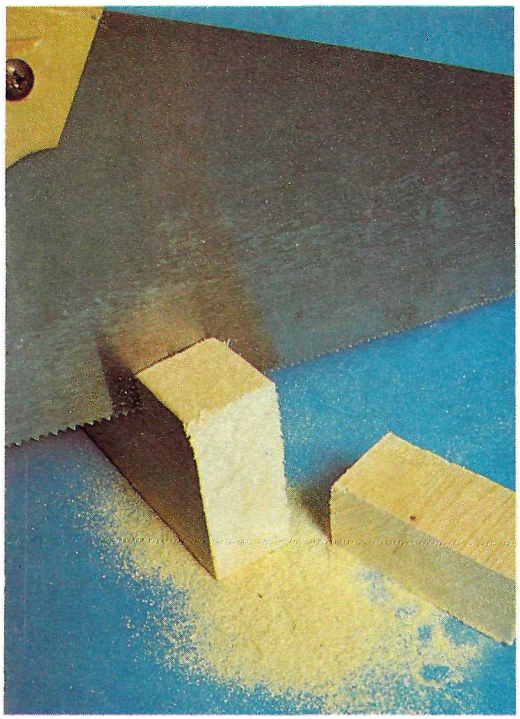
Hardness is another physical property. The harder the substance, the more difficult it is to scratch the surface of the substance. Geologists use this property to identify rocks and minerals. The diamond is the hardest naturally occurring substance. A diamond will scratch any other substance. Gold, on the other hand, is soft and easily scratched. Therefore, gold jewelry is made of a combination of gold and other metals that make the jewelry harder.

If you melt a silver spoon and shape the silver into a bracelet, the silver remains silver. The boiling point and melting point of a substance are physical properties. Each element has its own unique boiling point and melting point. Chlorine, which is a yellowish-green gas at room temperature, boils at −34.6°C and melts at −101.6°C. Iron melts at 1535°C and boils at 3000°C. The metal gallium melts in your hand because its melting point is 29.8°C.

Color, crystal shape, and density are other physical properties that sometimes help identify a substance. For example, sulfur crystals are typically bright yellow. Osmium is the densest element.

Magnetic properties are also physical properties. Iron is the most magnetic element. Nickel and cobalt are somewhat magnetic.





Producing Physical Changes

Iron can be hammered into sheets, molded into a radiator, or bent into a nail. During each change, the iron remains iron. A **physical change** is any change that does not alter the identity of a substance.

Sawing wood produces a physical change. The sawdust in the picture is still wood. Shredding paper and crushing a sugar cube are also physical changes. In each case, the identity of the substance—the wood, the paper, and the sugar—remains unchanged. In a physical change, the size, shape, or state of the substance changes. Boiling and freezing are, therefore, physical changes.

Dissolving sugar in tea is a physical change. The sugar no longer exists in the cube form, but the sugar is still sugar. You know the tea contains sugar because the tea tastes sweet. If you boil the tea, the water in it will boil away, but the sugar will remain.

Evaporation is a physical change from the liquid to the gaseous state. When water evaporates, the liquid changes to a gas. Condensation reverses the process.

At room temperature and under standard pressure, phosphorus is a white solid. If you heat phosphorus to 250°C in the absence of air, it turns red. The element phosphorus is still present, but its color changes. The color change occurs because the atoms move into a different crystal shape. But the new crystals are still phosphorus.

Under most conditions, carbon dioxide is a gas. When it is cooled, however, carbon dioxide becomes the white solid known as dry ice. Although the white solid looks different from the colorless gas, both substances are carbon dioxide.

Review It

1. List three physical properties of an element.
2. Describe three physical changes of elements.

Activity

Physical Properties

Purpose
To observe physical properties of substances.

Materials
- aluminum foil
- copper wire
- sulfur crystals
- zinc strips
- small hammer
- nail
- balance
- 50-mL graduated cylinder
- water
- safety goggles

Procedure
1. Copy the table shown. Put on your safety goggles.
2. Examine each substance. Describe its shape, color, state, and luster.
3. Record your observations in the table.
4. Scratch the surface of each substance with a nail. Record "yes" if the nail scratches it or "no" if the nail does not scratch it.
5. Try to reshape each substance by bending, hammering, or folding it. Record your results.
6. Use the balance to find the mass of each element. Record the masses.
7. Half-fill the graduated cylinder and record the height of the water.
8. Drop the zinc into the water. Record the new height of the water.
9. Subtract the water levels you measured in steps 7 and 8. The difference is the volume of the zinc.
10. Calculate and record zinc's density using: density = mass ÷ volume.
11. Repeat steps 7–10 for the other substances.
12. Classify the substances you tested according to their properties as metals or nonmetals.

Analysis
1. Explain how you can shape some substances and not others.
2. How are properties useful in classifying substances?
3. How have people used knowledge of the properties of elements to design the nail, wire, and foil?

Data chart

Element	Shape	Color	State	Luster	Scratch	Malleability	Density
Aluminum							
Copper							
Sulfur							
Zinc							

10–3 Chemical Properties and Changes

In the old days, prospectors mistook iron pyrite for the element gold. This mistake occurred so often that iron pyrite was called fool's gold. To learn which other properties prospectors consider in identifying gold, keep these questions in mind:

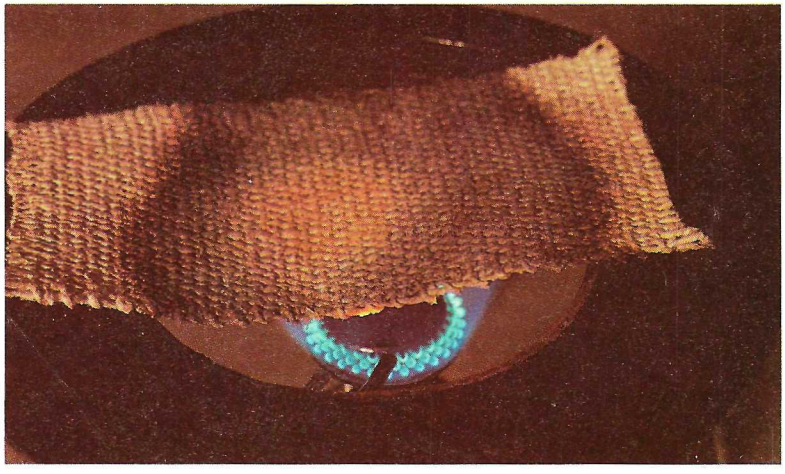
a. What is a chemical property?
b. What is a chemical change?

Identifying Chemical Properties

Two substances can look the same even if they are really quite different. To avoid mistaking them, we identify substances by more than one kind of property. A **chemical property** is a property that describes how a substance reacts with other substances.

You can observe a chemical property by trying to change a substance into a new material. If you add gold to nitric acid, gold remains unchanged. Gold does not react with the acid, so it does not become a new substance. If you add fool's gold to nitric acid, a new substance forms. Iron pyrite has the chemical property of reacting with acid.

If you ignite a piece of paper, the paper burns. It is flammable—at the proper temperature, it burns in the presence of oxygen. If we try to ignite asbestos, however, it does not burn. It is not flammable, as shown below.




Reacting with oxygen


Reacting with acid


Reacting with oxygen


Reacting with water

Producing Chemical Changes

A nail rusts because the iron in it reacts with oxygen in water. Silver tarnishes because it reacts with sulfur in the air. Reacting with air is a chemical property.

Rust and tarnish are new materials with new properties. Both result from **chemical changes,** which are changes that form new substances with new properties. The pictures show several chemical changes.

Many substances react with water or air. The bubbling or fizzing that sometimes results indicates a chemical change. Lithium, sodium, and potassium react so violently with water that an explosion results.

After a chemical change, the properties of the original substance are no longer present. Burning wood is a chemical change. The powdery, gray ash left behind by a burning log is not at all like wood.

Digesting food causes chemical changes. The substances in the carrot you eat and digest do not look like your skin. Yet your body changes the substances in carrots into the substances of skin—another chemical change.

Have You Heard?

Mixing wood ashes and water produces lye. Pioneers made lye in this way to make soap.

Review It

1. Name two chemical properties.
2. How can you tell if a chemical change has occurred?

Did You Know?

Naming the Elements

What is in a name? If you are talking about the elements, the answer is "many interesting stories!" For example, did you know that one element is named for a city in the United States and another is named for a state? They are element 97, berkelium, and element 98, californium. The two elements were given these names because they were first produced at the University of California at Berkeley.

Another popular way to name elements is after famous people. Samarium, for example, was named after the Russian mining engineer Samarski. Can you guess for whom the elements curium, fermium, einsteinium, and nobelium were named?

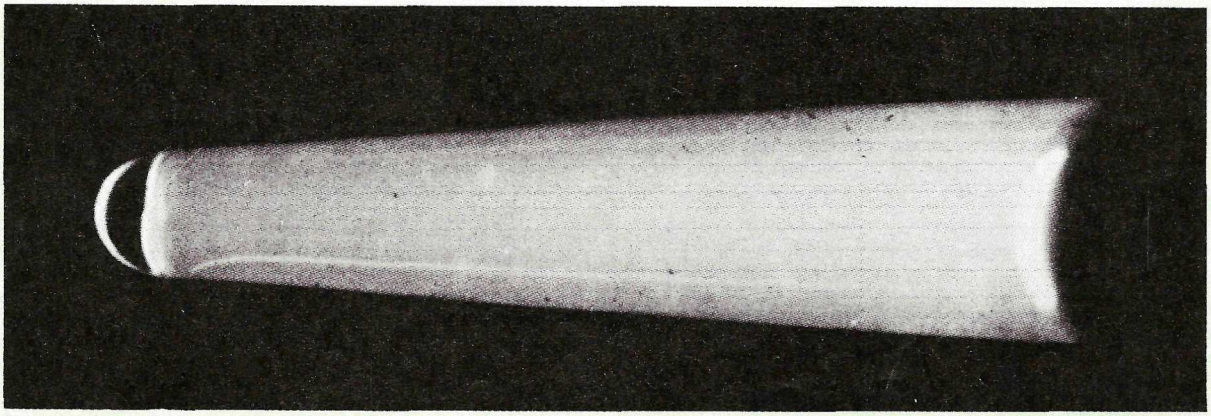
Sometimes scientists disagree about the naming of an element. Recently, elements 104, 105, and 106 were discovered by two different groups. The American discoverers wanted to call one element rutherfordium to honor Ernest Rutherford. The Russian discoverers wanted to name the same element kurchatovium after a Russian scientist. However, the International Union of Pure and Applied Chemistry has decided against both of these names. Instead, they suggest that all new elements be named after their atomic numbers. Element 104 would be called unnilquadium (un = 1, nil = 0, quad = 4); element 105, unnilpentium (pent = 5); and element 106, unnilhexium (hex = 6).

Elements that have been known for a long time are named from Latin or Greek words. Mercury's symbol, Hg, comes from *hydrargyrum,* which means "liquid silver." The symbol Au comes from the Latin name for gold, *aurum.* One ancient name may sound familiar to you. Lead, Pb from the Latin *plumbum,* was often used to make water pipes and drains. The people who repaired them were named after the element they used.

Many elements are named after one of their properties. For example, bromine comes from the Greek word *bromos,* which means "stink." How would you describe the nature of argon, knowing that *argos* means "idle"?

For Discussion

1. List some ways the elements were named.
2. What is the system now recommended for naming new elements?



A test tube containing a glowing curium compound

Chapter Summary

- An element is a pure substance that cannot be broken down into another substance by heat, light, or electricity. (10–1)
- An atom is the smallest particle of an element with the chemical characteristics of that element. (10–1)
- Metals have a shiny luster and are good conductors of heat and electricity. Some metals are malleable and ductile. (10–1)
- The properties of metals and nonmetals are generally opposites. (10–1)
- Metalloids are elements with properties of both metals and nonmetals. (10–1)
- A physical property distinguishes a substance without changing its nature. (10–2)
- Taste, odor, hardness, boiling and melting points, physical state, color, crystal shape, density, magnetic properties, luster, and being malleable, ductile, and a good conductor are physical properties. (10–2)
- A physical change is one that does not change the identity of a substance. (10–2)
- A chemical property explains how a substance reacts with other substances. (10–3)
- Reacting with air and acid are chemical properties. (10–3)
- A chemical change is a one that produces new substances with new properties. (10–3)

Interesting Reading

Coombs, Charles. *Gold and Other Precious Metals.* Describes the properties, uses, and refining of gold, silver, and platinum.

Wohlrabe, Raymond A. *Metals.* Lippincott, 1964. A classic history of our uses of metals, with home experiments that could be done with adult supervision. (Be sure to ask your parent's permission before performing any experiments at home.)

Questions/Problems

1. You perform certain tests on an unknown substance. How would you decide if it is an element or some other kind of substance?
2. Which properties of copper allow it to be used in an electrical wire, a cooking utensil, or a bracelet?
3. Which of the following statements about the element sodium refer to physical properties? Which refer to chemical properties? a) reacts violently with water; b) is a shiny metal; c) is so soft that a knife can cut it; d) will tarnish quickly if exposed to air.
4. You have a box of sugar cubes, a blender, some water, a pot, and a hot plate. What physical change or changes can you make in the sugar? What chemical change or changes can you make?
5. What could you do to keep an iron nail from rusting?

Extra Research

1. Gold is a very soft metal. Talk with a local jeweler to find out what is added to gold to make it stronger and less easy to bend.
2. Industry uses a lot of iron. But iron has some undesirable properties. Use an encyclopedia to find out how various industries use and improve iron.
3. Visit a museum to see samples of the elements. Or collect samples of as many elements as you can. Use chemistry or mineralogy books to help you identify each element.

Chapter Test

A. Vocabulary Write the numbers 1–10 on a piece of paper.
Match the definition in Column I with the term it defines in Column II.

Column I

1. a pure substance that cannot be broken down into another substance by heat, light, or electricity
2. can be hammered, rolled, or pounded into different shapes without being broken
3. can be drawn into a wire
4. how a substance shines
5. smallest particle of an element that acts like that element
6. the elements copper, aluminum, and gold
7. a change that maintains the substance's identity
8. a change that produces a new substance
9. the characteristics of color, odor, taste, and hardness
10. describes how a substance reacts with other substances

Column II

a. atom
b. chemical change
c. chemical property
d. ductile
e. element
f. luster
g. malleable
h. metals
i. physical change
j. physical property

B. Multiple Choice Write the numbers 1–10 on your paper.
Choose the letter that best completes the statement or answers the question.

1. An element forms from a) different kinds of atoms. b) metals. c) one kind of atom. d) nonmetals.

2. Which of the following is not an element? a) silver b) rust c) chlorine d) calcium

3. Tarnish on silver indicates a) a physical change. b) density. c) a chemical change. d) hardness.

4. Copper is a) malleable. b) a metal. c) ductile. d) a, b, and c.

5. The physical properties of gold include the fact that it a) is shiny. b) reacts with oxygen. c) is hard. d) reacts with acid.

6. Lead is a a) metal. b) nonmetal. c) metalloid. d) a and c.

7. Choose the correct statement. a) All elements are found in nature. b) Eighty-nine elements are found in nature. c) All elements are made in the laboratory. d) Eighty-nine elements are made in the laboratory.

8. A dull, yellow solid that conducts electricity is probably a a) metal. b) nonmetal. c) metalloid. d) none of the above.

9. In a physical change, the change is in a) size. b) state. c) shape. d) a, b, and c.

10. Iron and oxygen join to produce rust in a(n) a) chemical change. b) physical change. c) element. d) physical property.