CHAPTER 3 Matter—Properties and Changes

3.1 Properties of Matter

All of the material—the "stuff"—around us is matter. A **substance** is matter that has a uniform and unchanging composition. For example, water is a pure substance. No matter where it is found, a sample of water will have the same composition as any other sample of water.

A **physical property** of a substance is a characteristic that can be observed and measured without changing the composition of the substance. Words such as *hard*, *soft*, *shiny*, *dull*, *brittle*, *flexible*, *heavy* (in density), and *light* (in density) are used to describe physical properties.

A **chemical property** describes the ability of a substance to combine with or change into one or more other substances. For example, the ability of iron to form rust when combined with air is a chemical property of iron. The inability of a substance to combine with another substance is also a chemical property. For example, the inability to combine with most other substances is a chemical property of gold.

Practice Problems

1. Identify each of the following as an example of a physical property or a chemical property.

- **a.** Silver tarnishes when it comes in contact with hydrogen sulfide in the air.
- **b.** A sheet of copper can be pounded into a bowl.
- **c.** Barium melts at 725°C.
- **d.** Helium does not react with any other element.
- **e.** A bar of lead is more easily bent than is a bar of aluminum of the same size.
- **f.** Potassium metal is kept submerged in oil to prevent contact with oxygen or water.

g. Diamond dust can be used to cut or grind most other materials.

h. Rocks containing carbonates can be identified because they fizz when hydrochloric acid is applied.

Under ordinary conditions, matter exists in three different physical forms called the **states of matter**—solid, liquid, and gas. **Solid** matter has a definite shape and a definite volume. A solid is rigid and incompressible, so it keeps a certain shape and cannot be squeezed into a smaller volume. A solid has these properties because the particles that make up the solid are packed closely together and are held in a specific arrangement.

Liquid matter has a definite volume, like a solid, but flows and takes the shape of its container. A liquid is virtually incompressible because its particles are packed closely together. A liquid flows because the particles are held in no specific arrangement but are free to move past one another.

Like a liquid, a **gas** flows and takes the shape of its container, but has no definite volume and occupies the entire space of its container. Gaseous matter has these properties because its particles are free to move apart to fill the volume of the container. Also, because of the space between its particles, a gas can be compressed to a smaller volume. A **vapor** is the gaseous state of a substance that is a liquid or a solid at room temperature.

Practice Problems

2. Identify each of the following as a property of a solid, liquid, or gas. Some answers will include more than one state of matter.

a. flows and takes the shape of its container

b. compressible

c. made of particles held in a specific arrangement

d. has a definite volume

e. always occupies the entire space of its container

f. has a definite volume but flows

3.2 Changes in Matter

Matter can undergo two fundamental kinds of changes. Changes that do not alter the composition of matter are called **physical changes.** Phase changes, in which matter changes from one phase (or state) to another, are common examples of physical changes. The temperatures at which the phase changes of boiling and melting take place are important physical properties of substances.

A **chemical change** occurs when one or more substances change into new substances. A chemical change is also known as a **chemical reaction.** The appearance of new substances is the sign that a chemical reaction has occurred. In a chemical reaction, the substances present at the start are called **reactants.** The new substances that are formed in the reaction are called **products.** A chemical reaction is represented by a **chemical equation,** which shows the relationship between reactants and products.

Practice Problems

3. Identify each of the following as an example of a chemical change or a physical change.

- **a.** Moisture in the air forms beads of water on a cold windowpane.
- **b.** An electric current changes water into hydrogen and oxygen.
- **c.** Yeast cells in bread dough make carbon dioxide and ethanol from sugar.
- **d.** Olive oil, vinegar, salt, and pepper are shaken together to make salad dressing.
- **e.** Molten bronze is poured into a mold and solidifies to form a figurine.
- **f.** A reactant decomposes to form two products.

▶ **Conservation of Mass** Over two centuries ago, chemists established a fundamental law called the **law of conservation of mass.** This law states that during a chemical reaction, mass is neither lost nor gained. In other words, all the matter present at the start of a reaction still exists at the end of the reaction. The law of conservation of mass can be stated in mathematical form as follows.

$$\text{Mass}_{\text{reactants}} = \text{Mass}_{\text{products}}$$

Example Problem 1

Law of Conservation of Mass

A thin strip of iron with a mass of 15.72 g is placed into a solution containing 21.12 g of copper (II) sulfate and copper begins to form. After a while, the reaction stops because all of the copper(II) sulfate has reacted. The iron strip is found to have a mass of 8.33 g. The mass of copper formed is found to be 8.41 g. What mass of iron(II) sulfate has been formed in the reaction?

Solution Apply the law of conservation of mass.
In this reaction, there are two reactants and two products, so the law of conservation of mass can be restated as follows.

$$\text{Mass}_{\text{reactant 1}} + \text{Mass}_{\text{reactant 2}} = \text{Mass}_{\text{product 1}} + \text{Mass}_{\text{product 2}}$$

Rewrite the equation with the names of the reactants and products.

$$\text{Mass}_{\text{iron}} + \text{Mass}_{\text{copper sulfate}} = \text{Mass}_{\text{copper}} + \text{Mass}_{\text{iron sulfate}}$$

To find the mass of iron sulfate, rearrange the equation.

$$\text{Mass}_{\text{iron sulfate}} = \text{Mass}_{\text{iron}} + \text{Mass}_{\text{copper sulfate}} - \text{Mass}_{\text{copper}}$$

Then, determine the mass of iron that reacted.

$$\text{Mass}_{\text{iron}} = \text{original mass of iron} - \text{mass of iron remaining}$$

$$\text{Mass}_{\text{iron}} = 15.72\text{ g} - 8.33\text{ g} = 7.39\text{ g}$$

Finally, substitute the masses into the equation and solve.

$$\text{Mass}_{\text{iron sulfate}} = 7.39\text{ g} + 21.12\text{ g} - 8.41\text{ g} = 20.10\text{ g iron sulfate}$$

To check your work, make sure the sum of the masses of the reactants is equal to the sum of the masses of the products.

Practice Problems

4. A sealed glass tube contains 2.25 g of copper and 3.32 g of sulfur. The mass of the tube and its contents is 18.48 g. Upon heating, a reaction forms copper(II) sulfide (CuS). All of the copper reacts, but only 1.14 g of sulfur reacts. Predict what the mass of the tube and its contents will be after the reaction is completed. Explain your reasoning.

5. When heated, calcium hydroxide and ammonium chloride react to produce ammonia gas, water vapor, and solid calcium chloride. Suppose 5.00 g of calcium hydroxide and 10.00 g of ammonium chloride are mixed in a test tube and heated until no more ammonia is given off. The remaining material in the test tube has a mass of 10.27 g. What total mass of ammonia and water vapor was produced in the reaction?

6. When a solution of barium nitrate and a solution of copper(II) sulfate are mixed, a chemical reaction produces solid barium sulfate, which sinks to the bottom, and a solution of copper(II) nitrate. Suppose some barium nitrate is dissolved in 120.00 g of water and 8.15 g of copper(II) sulfate is dissolved in 75.00 g of water. The solutions are poured together, and a white solid forms. After the solid is filtered off, it is found to have a mass of 10.76 g. The mass of the solution that passed through the filter is 204.44 g. What mass of barium nitrate was used in the reaction?

7. A reaction between sodium hydroxide and hydrogen chloride gas produces sodium chloride and water. A reaction of 22.85 g of sodium hydroxide with 20.82 g of hydrogen chloride gives off 10.29 g of water. What mass of sodium chloride is formed in the reaction?

3.3 Mixtures of Matter

A **mixture** is a combination of two or more pure substances in which each substance retains its individual properties. Concrete, most rocks, most metal objects, all food, and the air you breathe are mixtures that are often composed of many different substances. The composition of a mixture is variable. For example, the composition of salt water can be varied by changing the amount of salt or water in the mixture.

Two types of mixtures exist. A **heterogeneous mixture** is one that is not blended smoothly throughout. Examples of heterogeneous mixtures include smoky air and muddy water. You may have to use a magnifying glass or even a microscope, but if you can identify bits of one or more of the components of a mixture, the mixture is heterogeneous.

A **homogeneous mixture** is one that has a constant composition throughout. By dissolving sugar in water, you create a homogeneous mixture. A homogeneous mixture is also called a **solution.** In solutions, the atoms and/or molecules of two or more substances are completely mingled with one another. Solutions do not have to be solids dissolved in liquids; they can be mixtures of various states of matter. For example, air is a gaseous solution containing nitrogen, oxygen, argon, carbon dioxide, water vapor, and small amounts of other gases. An **alloy** is a homogeneous mixture (solution) of two or more metals or of metals and nonmetals. Alloys are considered to be solid solutions.

Practice Problems

8. Identify each of the following as an example of a homogeneous mixture or a heterogeneous mixture.

- **a.** 70% isopropyl rubbing alcohol
- **b.** a pile of rusty iron filings
- **c.** concrete
- **d.** saltwater
- **e.** gasoline
- **f.** bread

3.4 Elements and Compounds

Pure substances are classified into two categories—elements and compounds. An **element** is a substance that cannot be separated into simpler substances. Oxygen, carbon, sulfur, aluminum, iron, and gold are elements. More than 110 elements are known, but only 91 occur naturally on Earth. The remainder have been created by scientists.

Each element may be represented by a one- or two-letter symbol. In the mid-nineteenth century, a Russian chemist, Dmitri Mendeleev, saw that elements could be arranged according to repeating patterns of properties. Mendeleev's arrangement has evolved into the **periodic table** of the elements that you can see inside the back cover of this Handbook. The vertical columns of elements are called **groups** or **families.** The elements in a group have similar properties. Horizontal rows on the periodic table are called **periods.** When a new period starts, the elements tend to repeat the properties of the elements above them in the previous period. The value of Mendeleev's table was that it correctly predicted the properties of elements that had not yet been discovered.

A **compound** is a substance that consists of two or more elements chemically combined. The elements in a compound are not simply mingled together as they are in a mixture. Instead, they are combined in a way such that the compound has properties that are different from those of the elements of which it is composed. Each compound is represented by a formula, a combination of the symbols of the elements that make up the compounds. You may already know some chemical formulas such as H_2O for water, NaCl for table salt, and NH_3 for ammonia.

Practice Problems

9. Identify each of the following as an example of an element or a compound.

- **a.** sucrose (table sugar)
- **b.** the helium in a balloon
- **c.** baking soda
- **d.** a diamond

e. aluminum foil

f. the substances listed on the periodic table

g. calcium chloride pellets used to melt ice

A given compound is always composed of the same elements in the same proportion by mass. This fact is known as the **law of definite proportions.** For example, 100.00 g of H_2O always contains 11.19 g of hydrogen and 88.81 g of oxygen, no matter where the water came from. Compounds are often identifiable from their percentage composition, the **percent by mass** of each element in a compound. The percent by mass of each element in a compound may be found by using the following equation.

$$\text{Percent by mass of an element (\%)} = \frac{\text{mass of element}}{\text{mass of compound}} \times 100\%$$

For example, suppose you break a compound down into its elements and find that 25.00 g of the compound is composed of 6.77 g of tin and 18.23 g of bromine. The percent by mass of tin in the compound can be determined as follows.

$$\text{Percent by mass of tin} = \frac{\text{mass of tin}}{\text{mass of compound}} \times 100\%$$

$$\text{Percent by mass of tin} = \frac{6.77 \text{ g}}{25.00 \text{ g}} \times 100\% = 27.1\% \text{ tin}$$

Practice Problems

10. Follow the procedure described above to determine the percent by mass of bromine in the compound discussed above. What is the sum of the percents of the two elements?

11. A 134.50-g sample of aspirin is made up of 6.03 g of hydrogen, 80.70 g of carbon, and 47.77 g of oxygen. What is the percent by mass of each element in aspirin?

12. A 2.89-g sample of sulfur reacts with 5.72 g of copper to form a black compound. What is the percentage composition of the compound?

13. Aluminum oxide has a composition of 52.9% aluminum and 47.1% oxygen by mass. If 16.4 g of aluminum reacts with oxygen to form aluminum oxide, what mass of oxygen reacts?

Chapter 3 Review

14. How does a pure substance differ from a mixture of substances such as lemonade?

15. Identify each of the following as an example of a physical property or a chemical property.

- **a.** A piece of silver can be hammered into a cloverleaf shape.
- **b.** A piece of charcoal, which is mostly the substance carbon, glows red, gives off heat, and becomes a gray ash.
- **c.** Table salt dissolves in water and remains as a crust when the water evaporates.
- **d.** The Statue of Liberty, once the color of a new penny, turned to a bluish-green as it formed a thin coating called a patina.

16. Can two different samples of the same substance have different physical properties? Can they have different chemical properties? Explain your answers to both questions.

17. Write one statement each for a solid, a liquid, and a gas describing the particle arrangement and spacing in each state.

18. Suppose you measure the mass of an iron nail and find it to be 13.8 g. You place the nail in a moist place for two weeks. When you retrieve the nail, it is covered with a crusty brown coating of rust. You then place the nail on a balance to measure its mass. Will the nail have a mass that is greater than, less than, or equal to 13.8 g? Explain your answer.

19. Identify each of the following examples as a physical change or a chemical change.

- **a.** Wood burns in a fireplace.
- **b.** A block of pewter is pounded and made into a bowl.
- **c.** A copper weather vane becomes green in a few years.
- **d.** Baking soda in cookie dough causes the cookies to puff with bubbles of gas when they are baked.

- **e.** A pan of water boils on a stove until the pan becomes dry.
- **f.** Soap and water are used to clean up a spill of grease.
- **g.** Mothballs vaporize in a closed closet.

20. Aluminum can combine chemically with various substances, but it never reacts to form simpler substances. Is aluminum an element, a compound, or a mixture? How do you know? Is aluminum a substance? Explain.

21. The mineral cassiterite is mined as a commercial source of tin. It is a compound of the elements tin and oxygen. A 1.000-kg sample of pure cassiterite mined in Germany contains 788 g of tin. Is it possible to predict the mass of tin contained in a 43.5-kg sample of cassiterite mined in South America? Explain your reasoning.

22. The elements carbon and sulfur are solids at room temperature. Can you reasonably predict that a compound of these two elements will also be a solid at room temperature? Explain your conclusion.