CHAPTER 3

Matter—Properties and Changes

BIG Idea Everything is made of matter.

3.1 Properties of Matter

MAIN Idea Most common substances exist as solids, liquids, and gases, which have diverse physical and chemical properties.

3.2 Changes in Matter

MAIN Idea Matter can undergo physical and chemical changes.

3.3 Mixtures of Matter

MAIN Idea Most everyday matter occurs as mixtures—combinations of two or more substances.

3.4 Elements and Compounds

MAIN Idea A compound is a combination of two or more elements.

ChemFacts

- Water is the only common substance on Earth that exists naturally as a solid, a liquid, and a gas.
- Water always has the same composition, whether it is frozen in ice cubes, flowing in a river, or in the air as water vapor.
- About 70% of the surface of Earth is covered with water.

Start-Up Activities

LAUNCH Lab

How can you observe chemical change?

Many objects in the everyday world do not change very much over time. However, when substances are mixed together, change is possible.

Procedure

1. Read and complete the lab safety form.
2. Place a **piece of zinc metal** in a **large test tube.**
3. Place the test tube in a **ring stand** and attach the clamp to a ring stand so that the mouth of the test tube is pointing away from you.
4. Measure 10 mL of **3*M* hydrochloric acid** in a **graduated cylinder,** and place it on the benchtop.
   WARNING: ***HCl could cause burns and produce hazardous fumes.***
5. Light a **wood splint** with a **match.** Dispose of the match as directed by your teacher. Allow the wood to burn for 5 s, then blow out the flame to leave a glowing ember.
6. Place the glowing ember at the mouth of the tube, then move the ember to the mouth of the graduated cylinder. Record your observation.
   WARNING: ***Be sure the test tube is facing away from you when the splint is brought near.***
7. Dispose of the ember as directed by your teacher.
8. Carefully pour the hydrochloric acid into the test tube.
9. Wait 1 min. Repeat Step 5.
10. Place the ember at the mouth of the tube. Record your observations.

Analysis

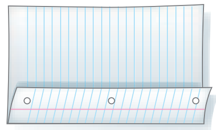
1. **Describe** any changes you observed during the test.
2. **Infer** What caused the bubbles to form when you added the hydrochloric acid to the zinc metal?
3. **Infer** What happened to the glowing ember in Step 10? Why did this not happen in Step 6?

Inquiry Why did you wait before using the wood splint? Design an experiment to determine if the results vary over time.

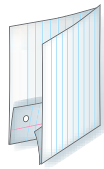
FOLDABLES™ Study Organizer

Properties and Changes Make a Foldable to help you organize your study of the chemical and physical changes and properties of matter.

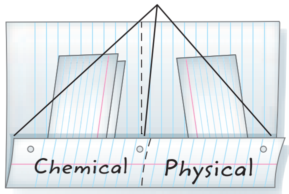
STEP 1 Fold up the bottom of a horizontal sheet of paper about 5 cm as shown.



STEP 2 Fold the paper in half.



STEP 3 Unfold once and staple to make two pockets. Label the pockets *Chemical* and *Physical*.



FOLDABLES Use this Foldable with Sections 3.1 and 3.2. As you read the sections, use index cards or quarter-sheets of paper to summarize what you learn about the properties and changes of matter. Insert these into the appropriate pockets of your Foldable.

Chemistry Online

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Section 3.1

Objectives

- **Identify** the characteristics of a substance.
- **Distinguish** between physical and chemical properties.
- **Differentiate** among the physical states of matter.

Review Vocabulary

density: a ratio that compares the mass of an object to its volume

New Vocabulary

states of matter
solid
liquid
gas
vapor
physical property
extensive property
intensive property
chemical property

Properties of Matter

MAIN Idea Most common substances exist as solids, liquids, and gases, which have diverse physical and chemical properties.

Real-World Reading Link Picture a glass of ice water. The ice floats, and you know the ice will eventually melt if left long enough at room temperature. When the water changes from solid to liquid, does the composition of the water also change?

Substances

As you know, matter is anything that has mass and takes up space. Everything around us is matter, including things that we cannot see, such as air and microbes. For example, table salt is a simple type of matter that you are probably familiar with. Table salt has a unique and unchanging chemical composition. Its chemical name is sodium chloride. It is always 100% sodium chloride, and its composition does not change from one sample to another. Salt harvested from the sea or extracted from a mine, as shown in **Figure 3.1,** always has the same composition and properties.

Recall from Chapter 1 that matter with a uniform and unchanging composition is called a substance, also known as a pure substance. Table salt is a pure substance. Another example of a pure substance is pure water. Water is always composed of hydrogen and oxygen. Seawater and tap water, on the other hand, are not pure substances because samples taken from different locations will often have different compositions. That is, the samples will contain different amounts of water, minerals, and other dissolved substances. Substances are important; much of your chemistry course will be focused on the composition of substances and how they interact with one another.

Figure 3.1 Whether harvested from the sea or extracted from a mine, salt always has the same composition.


Salt from the sea


Salt from a mine

■ **Figure 3.2** A solid has a definite shape and does not take the shape of its container. Particles in a solid are tightly packed.

States of Matter

Imagine you are sitting on a bench, breathing heavily and drinking water after playing a game of soccer. You are in contact with three different forms of matter—the bench is a solid, the water is a liquid, and the air you breathe is a gas. In fact, all matter that exists naturally on Earth can be classified as one of these physical forms, which are called **states of matter.** Each of the three common states of matter can be distinguished by the way it fills a container. Scientists also recognize other states of matter. One of them is called plasma. It can occur in the form of lightning bolts and in stars.

Reading Check **Name** and define the common states of matter.

Solids A **solid** is a form of matter that has its own definite shape and volume. Wood, iron, paper, and sugar are all examples of solids. The particles of matter in a solid are tightly packed; when heated, a solid expands, but only slightly. Because its shape is definite, a solid might not conform to the shape of the container in which it is placed. If you place a rock into a container, the rock will not take the shape of the container, as shown in **Figure 3.2.** The tight packing of particles in a solid makes it incompressible; that is, it cannot be pressed into a smaller volume. It is important to understand that a solid is not defined by its rigidity or hardness. For instance, although concrete is rigid and wax is soft, they are both solids.

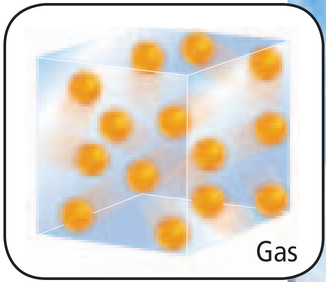
Liquids A **liquid** is a form of matter that flows, has constant volume, and takes the shape of its container. Common examples of liquids include water, blood, and mercury. The particles in a liquid are not rigidly held in place and are less closely packed than the particles in a solid. Liquid particles are able to move past each other. This property allows a liquid to flow and take the shape of its container, as shown in **Figure 3.3,** although it might not completely fill the container,

A liquid's volume is constant: regardless of the size and shape of the container in which the liquid is held, the volume of the liquid remains the same. Because of the way the particles of a liquid are packed, liquids are virtually incompressible. Like solids, however, liquids tend to expand when they are heated.

Reading Check **Compare** the properties of solids and liquids in terms of their particle arrangements.

■ **Figure 3.3** A liquid takes the shape of its container. Particles in a liquid are not rigidly held in place.

Figure 3.4 Gases take the shape and volume of their containers. Particles in a gas are very far apart.



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Concepts In Motion

Interactive Figure To see an animation of the three common states of matter, visit glencoe.com.

Gases A **gas** is a form of matter that not only flows to conform to the shape of its container but also fills the entire volume of its container, as shown in **Figure 3.4.** If you fill a container with gas and close the container, the gas will expand to fill the container. Compared to solids and liquids, the particles of gases are very far apart. Because of the significant amount of space between particles, gases are easily compressed.

You are probably familiar with the word *vapor* as it relates to the word *gas*. However, the words *gas* and *vapor*, while similar, do not mean the same thing, and should not be used interchangeably. The word *gas* refers to a substance that is naturally in the gaseous state at room temperature. The word **vapor** refers to the gaseous state of a substance that is a solid or a liquid at room temperature. For example, steam is a vapor because water exists as a liquid at room temperature.

Reading Check **Differentiate** between gas and vapor.

PROBLEM-SOLVING LAB

Recognize Cause and Effect

How is compressed gas released? Tanks of compressed gases are common in chemistry laboratories. For example, nitrogen is often flowed over a reaction in progress to displace other gases that might interfere with the experiment. Given what you know about gases, explain how the realease of compressed nitrogen is controlled.

Analysis

The particles of gases are far apart, and gases tend to fill their containers—even if the container is a laboratory room. Tanks of compressed gas come from the supplier capped to prevent the gas from escaping. In the lab, a chemist or technician attaches a regulator to the tank and secures the tank to a stable fixture.

Think Critically

1. **Explain** why the flow of a compressed gas must be controlled for practical and safe use.
2. **Predict** what would happen if the valve on a full tank of compressed gas were suddenly opened all the way or if the tank were accidentally punctured.

Table 3.1	Physical Properties of Common Substances				
Substance	Color	State at 25 °C	Melting Point (°C)	Boiling Point (°C)	Density (g/cm^3)
Oxygen	colorless	gas	−218	−183	0.0014
Mercury	silver	liquid	−39	357	13.5
Water	colorless	liquid	0	100	1.00
Sucrose	white	solid	185	decomposes	1.59
Sodium chloride	white	solid	801	1413	2.17

Physical Properties of Matter

You are probably used to identifying objects by their properties—their characteristics and behavior. For example, you can easily identify a pencil in your backpack because you recognize its shape, color, weight, or some other property. These characteristics are all physical properties of the pencil. A **physical property** is a characteristic that can be observed or measured without changing the sample's composition. Physical properties also describe pure substances. Because substances have uniform and unchanging compositions, they also have consistent and unchanging physical properties. Density, color, odor, hardness, melting point, and boiling point are common physical properties that scientists record as identifying characteristics of a substance. **Table 3.1** lists several common substances and their physical properties.

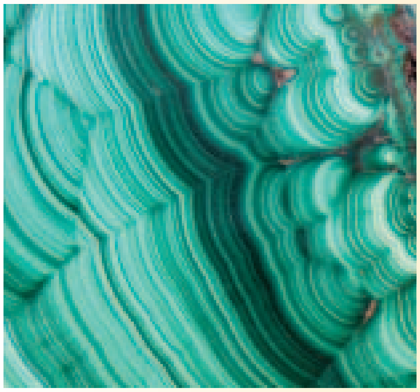
Reading Check **Define** *physical property* and provide examples.

Extensive and intensive properties Physical properties can be further described as being one of two types. **Extensive properties** are dependent on the amount of substance present. For example, mass is an extensive property. Length and volume are also extensive properties. Density, on the other hand, is an example of an intensive property of matter. **Intensive properties** are independent of the amount of substance present. For example, the density of a substance (at constant temperature and pressure) is the same no matter how much substance is present.

A substance can often be identified by its intensive properties. In some cases, a single intensive property is unique enough for identification. For instance, most of the spices shown in **Figure 3.5** can be identified by their scent.

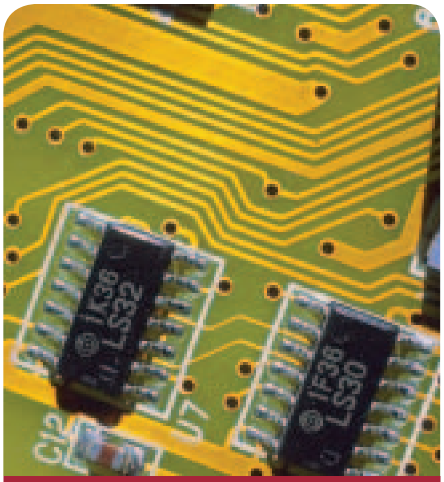
Figure 3.5 Many spices can be identified by their scent, which is an intensive property.
Infer *Name an extensive property of one of the spices pictured.*

Real-World Chemistry
Physical Properties

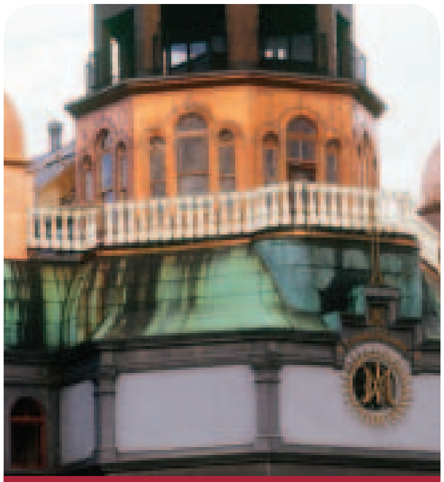


Minerals Scientists use physical properties such as color and hardness to identify minerals. For instance, malachite is always green and relatively soft. Malachite was used as a pigment in paint and is now mainly used to make jewelry.

Figure 3.6 One of the physical properties of copper is that it can be shaped into different forms, such as the wires on circuit boards. The fact that copper turns from reddish to green when reacting with substances in the air is a chemical property.



Copper wires


Copper roof

FOLDABLES Incorporate information from this section into your Foldable.

Chemical Properties of Matter

Some properties of a substance are not obvious unless the substance has changed composition as a result of its contact with other substances or the application of thermal or electric energy. The ability of a substance to combine with or change into one or more other substances is called a **chemical property.**

Iron forming rust when combined with the oxygen in air is an example of a chemical property of iron. Similarly, the inability of a substance to change into another substance is also a chemical property. For example, when iron is placed in nitrogen gas at room temperature, no chemical change occurs.

Reading Check **Compare** physical and chemical properties.

Observing Properties of Matter

Every substance has its own unique set of physical and chemical properties. **Figure 3.6** shows physical and chemical properties of copper. Copper can be shaped into different forms, which is a physical property. When copper is in contact with air for a long time, it reacts with the substances in the air and turns green. This is a chemical property. **Table 3.2** lists several physical and chemical properties of copper.

Table 3.2 Properties of Copper

Physical Properties	Chemical Properties
• reddish brown, shiny • easily shaped into sheets (malleable) and drawn into wires (ductile) • a good conductor of heat and electricity • density = 8.92 g/cm^3 • melting point = 1085°C • boiling point = 2570°C	• forms green copper carbonate compound when in contact with moist air • forms new substances when combined with nitric acid and sulfuric acid • forms a deep-blue solution when in contact with ammonia

■ **Figure 3.7** Because the density of ice is lower than the density of water, icebergs float on the ocean.

Properties and states of matter The properties of copper listed in **Table 3.2** might vary depending on the conditions under which they are observed. Because the particular form, or state, of a substance is a physical property, changing the state introduces or adds another physical property to its characteristics. It is important to state the specific conditions, such as temperature and pressure, under which observations are made because both physical and chemical properties depend on these conditions. Resources that provide tables of physical and chemical properties of substances, such as the *CRC Handbook of Chemistry and Physics,* generally include the physical properties of substances in all of the states in which they can exist.

Consider the properties of water, for example. You might think of water as a liquid (physical property) which is not particularly chemically reactive (chemical property). You might also know that water has a density of 1.00 g/cm^3 (physical property). These properties, however, apply only to water at standard temperature and pressure. At temperatures greater than 100°C, water is a gas (physical property) with a density of about 0.0006 g/cm^3 (physical property) that reacts rapidly with many different substances (chemical property). Below 0°C, water is a solid (physical property) with a density of about 0.92 g/cm^3 (physical property). The lower density of ice accounts for the fact that icebergs float on the ocean, as shown in **Figure 3.7.** Clearly, the properties of water are dramatically different under different conditions.

VOCABULARY

ACADEMIC VOCABULARY

Environment

the circumstances, objects, or conditions by which one is surrounded

Some animals can adapt to changes that occur in their environment.

Section 3.1 Assessment

Section Summary

- The three common states of matter are solid, liquid, and gas.
- Physical properties can be observed without altering a substance's composition.
- Chemical properties describe a substance's ability to combine with or change into one or more new substances.
- External conditions can affect both physical and chemical properties.

1. MAIN Idea **Create** a table that describes the three common states of matter in terms of their shape, volume, and compressibility.
2. **Describe** the characteristics that identify a sample of matter as a substance.
3. **Classify** each of the following as a physical or a chemical property.
   a. Iron and oxygen form rust.
   b. Iron is more dense than aluminum.
   c. Magnesium burns brightly when ignited.
   d. Oil and water do not mix.
   e. Mercury melts at −39°C.
4. **Organize** Create a chart that compares physical and chemical properties. Give two examples for each type of property.

Section 3.2

Objectives

- **Define** physical change and list several common physical changes.
- **Define** chemical change and list several indications that a chemical change has taken place.
- **Apply** the law of conservation of mass to chemical reactions.

Review Vocabulary

observation: orderly, direct information gathering about a phenomenon

New Vocabulary

physical change
phase change
chemical change
law of conservation of mass

Changes in Matter

MAIN Idea **Matter can undergo physical and chemical changes.**

Real-World Reading Link In a grill, the charcoal is initially a black solid that changes to a glowing red color and eventually ends up as ashes, carbon dioxide, and water. It changes as a result of its physical and chemical properties.

Physical Changes

A substance often undergoes changes that result in a dramatically different appearance yet leave the composition of the substance unchanged. An example is the crumpling of aluminum foil. While the foil goes from a smooth, flat, mirrorlike sheet to a round, compact ball, the actual composition of the foil is unchanged—it is still aluminum. A change such as this, which alters a substance without changing its composition, is known as a **physical change.** Cutting a sheet of paper and breaking a crystal are other examples of physical changes in matter.

Phase change As with other physical properties, the state of matter depends on the temperature and pressure of the surroundings. As temperature and pressure change, most substances undergo a change from one state (or phase) to another. A **phase change** is a transition of matter from one state to another.

Connection to Earth Science **The water cycle** This is the case with the water cycle, which allows life to exist on Earth. At atmospheric pressure and at temperatures below 0°C, water is in its solid state, which is known as ice. As heat is added to the ice, it melts and becomes liquid water. This change of state is a physical change because even though ice and water have different appearances, they have the same composition. If the temperature of the water increases to 100°C, the water begins to boil and liquid water is converted to steam. Melting and formation of a gas are both physical changes and phase changes. **Figure 3.8** shows condensation and solidification, two common phase changes. Terms such as *boil, freeze, condense, vaporize,* or *melt* in chemistry generally refer to a phase change in matter.

Figure 3.8 Condensation can occur when a gas is in contact with a cool surface, causing droplets to form. Solidification occurs when a liquid cools. Water dripping from the roof forms icicles as it cools.


Condensation


Solidification

The temperature and pressure at which a substance undergoes a phase change are important physical properties. These properties are called the melting and boiling points of the substance. Look again at **Table 3.1** to see this information for several common substances. Like density, the melting and boiling points are intensive physical properties that can be used to identify unknown substances. Tables of intensive properties, such as those given at the end of this textbook or in the *CRC Handbook of Chemistry and Physics*, are useful tools in identifying unknown substances from experimental data.

Chemical Changes

A process that involves one or more substances changing into new substances is called a **chemical change,** commonly referred to as a chemical reaction. The new substances formed in the reaction have different compositions and different properties from the substances present before the reaction occurred. For example, the formation of rust when iron reacts with oxygen in the air is a chemical change. Rust, shown in **Figure 3.9,** is a chemical combination of iron and oxygen.

In chemical reactions, the starting substances are called reactants, and the new substances that are formed are called products. Terms such as *decompose*, *explode*, *rust*, *oxidize*, *corrode*, *tarnish*, *ferment*, *burn*, or *rot* generally refer to chemical reactions.

Reading Check **Define** *chemical change*.

Evidence of a chemical reaction As **Figure 3.9** shows, rust is a brownish-orange powdery substance that looks very different from iron and oxygen. Rust is not attracted to a magnet, whereas iron is. The observation that the product (rust) has different properties than the reactants (iron and oxygen) is evidence that a chemical reaction has taken place. A chemical reaction always produces a change in properties. Spoiled food, such as rotten fruit and bread, is another example of chemical reactions. The properties of spoiled food, like its taste and its digestibility, differ from fresh food. Examples of food that has undergone chemical reactions are shown in **Figure 3.9.**

Conservation of Mass

It was only in the late eighteenth century that scientists began to use quantitative tools to study and monitor chemical changes. The analytical balance, which was capable of measuring small changes in mass, was developed at that time. By carefully measuring mass before and after many chemical reactions, it was observed that, although chemical changes occurred, the total mass involved in the reaction remained constant. Assuming this was true for all reactions, chemists summarized this observation in a scientific law. The **law of conservation of mass** states that mass is neither created nor destroyed during a chemical reaction—it is conserved. In other words, the mass of the reactants equals the mass of the products. The equation form of the law of conservation of mass is as follows.

The Law of Conservation of Mass

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

Mass is conserved in a chemical reaction; products have the same mass as reactants.

FOLDABLES Incorporate information from this section into your Foldable.

Figure 3.9 When iron rusts and food rots, new substances are formed due to chemical change.
Identify *the reactants and the products in the formation of rust.*

EXAMPLE Problem 3.1

Math Handbook Solving Algebraic Equations pages 954–955

Conservation of Mass In an experiment, 10.00 g of red mercury(II) oxide powder is placed in an open flask and heated until it is converted to liquid mercury and oxygen gas. The liquid mercury has a mass of 9.26 g. What is the mass of oxygen formed in the reaction?

1 Analyze the Problem

You are given the mass of a reactant and the mass of one of the products in a chemical reaction. According to the law of mass conservation, the total mass of the products must equal the total mass of the reactants.

Known

$m_{\text{mercury(II) oxide}} = 10.00 \text{ g}$

$m_{\text{mercury}} = 9.26 \text{ g}$

Unknown

$m_{\text{oxygen}} = ? \text{ g}$

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2 Solve for the Unknown

$\text{Mass}_{\text{reactants}} = \text{Mass}_{\text{products}}$ State the law of conservation of mass.

$m_{\text{mercury(II) oxide}} = m_{\text{mercury}} + m_{\text{oxygen}}$

$m_{\text{oxygen}} = m_{\text{mercury(II) oxide}} - m_{\text{mercury}}$ Solve for m_{oxygen}.

$m_{\text{oxygen}} = 10.00 \text{ g} - 9.26 \text{ g}$ Substitute $m_{\text{mercury(II) oxide}} = 10.00 \text{ g}$ and $m_{\text{mercury}} = 9.26 \text{ g}$.

$m_{\text{oxygen}} = \mathbf{0.74 \text{ g}}$

3 Evaluate the Answer

The sum of the masses of the two products equals the mass of the reactant, verifying that mass has been conserved. The answer is correctly expressed to the hundredths place, making the number of significant digits correct.

PRACTICE Problems

Extra Practice Page 977 and glencoe.com

5. Use the data in the table to answer the following questions.

Aluminum and Liquid Bromine Reaction

Substance	Before Reaction	After Reaction
Aluminum	10.3 g	0.0 g
Liquid bromine	100.0 g	8.5 g
Compound	0.0 g	

How many grams of bromine reacted? How many grams of compound were formed?

6. From a laboratory process designed to separate water into hydrogen and oxygen gas, a student collected 10.0 g of hydrogen and 79.4 g of oxygen. How much water was originally involved in the process?

7. A student carefully placed 15.6 g of sodium in a reactor supplied with an excess quantity of chlorine gas. When the reaction was complete, the student obtained 39.7 g of sodium chloride. Calculate how many grams of chlorine gas reacted. How many grams of sodium reacted?

8. A 10.0-g sample of magnesium reacts with oxygen to form 16.6 g of magnesium oxide. How many grams of oxygen reacted?

9. **Challenge** 106.5 g of HCl(g) react with an unknown amount of NH_3(g) to produce 157.5 g of NH_4Cl(s). How many grams of NH_3(g) reacted? Is the law of conservation of mass observed in the reaction? Justify your answer.

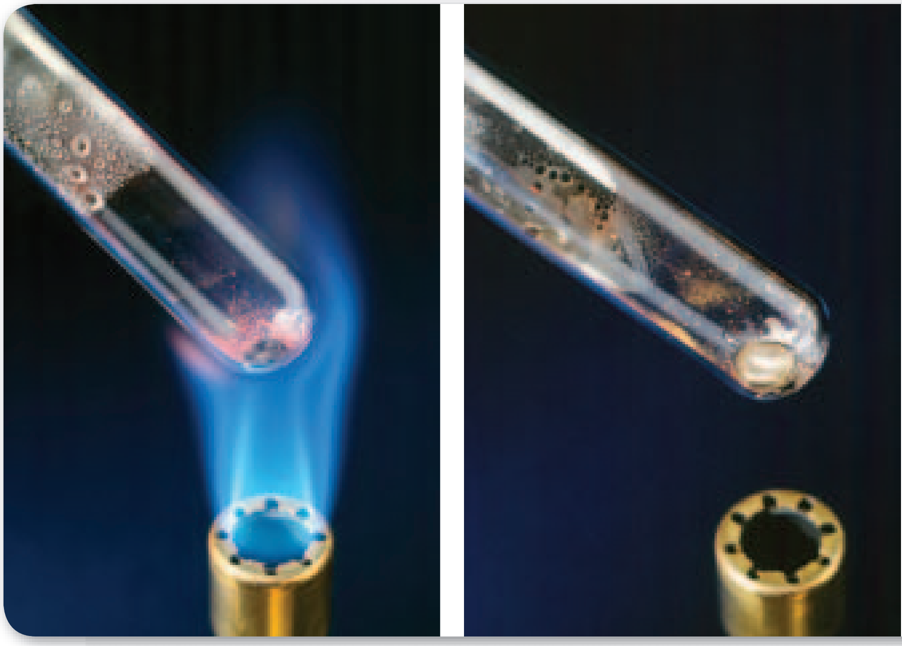


Figure 3.10 When mercury(II) oxide is heated, it reacts to form liquid mercury and oxygen gas. The sum of the masses of liquid mercury and oxygen gas produced during the reaction equals the mass of the mercury oxide.

CLICK HERE

Concepts In Motion

Interactive Figure To see an animation of the conservation of mass, visit glencoe.com.

French scientist Antoine Lavoisier (1743–1794) was one of the first to use an analytical balance to monitor chemical reactions. He studied the thermal decomposition of mercury(II) oxide, known then as *calx of mercury.* Mercury(II) oxide, shown in **Figure 3.10,** is a powdery red solid. When it is heated, the red solid reacts to form silvery liquid mercury and colorless oxygen gas. The color change and production of a gas are indicators of a chemical reaction. When the reaction occurs in a closed container, the oxygen gas cannot escape and the mass before and after the reaction can be measured. The masses will be the same. The law of conservation of mass is one of the most fundamental concepts of chemistry.

Section 3.2 Assessment

Section Summary

- A physical change alters the physical properties of a substance without changing its composition.
- A chemical change, also known as a chemical reaction, involves a change in a substance's composition.
- In a chemical reaction, reactants form products.
- The law of conservation of mass states that mass is neither created nor destroyed during a chemical reaction; it is conserved.

10. MAIN Idea **Classify** each example as a physical change or a chemical change.
- **a.** crushing an aluminum can
- **b.** recycling used aluminum cans to make new aluminum cans
- **c.** aluminum combining with oxygen to form aluminum oxide

11. Describe the results of a physical change and list three examples of physical change.

12. Describe the results of a chemical change. List four indicators of chemical change.

13. Calculate Solve each of the following.
- **a.** In the complete reaction of 22.99 g of sodium with 35.45 g of chlorine, what mass of sodium chloride is formed?
- **b.** A 12.2-g sample of *X* reacts with a sample of *Y* to form 78.9 g of *XY*. What is the mass of *Y* that reacted?

14. Evaluate A friend tells you, "Because composition does not change during a physical change, the appearance of a substance does not change." Is your friend correct? Explain.

Section 3.3

Objectives

- **Contrast** mixtures and substances.
- **Classify** mixtures as homogeneous or heterogeneous.
- **List** and describe several techniques used to separate mixtures.

Review Vocabulary

substance: a form of matter that has a uniform and unchanging composition; also known as a pure substance

New Vocabulary

mixture
heterogeneous mixture
homogeneous mixture
solution
filtration
distillation
crystallization
sublimation
chromatography

Mixtures of Matter

MAIN Idea Most everyday matter occurs as mixtures—combinations of two or more substances.

Real-World Reading Link That familiar hiss when you open a soft-drink bottle is the sound of gas escaping. You might have noticed that when you leave the bottle opened, eventually most of the carbon dioxide, will escape. But the soft drink will remain sweet no matter how long you leave the bottle opened.

Mixtures

You have already read that a pure substance has a uniform and unchanging composition. What happens when two or more subtances are combined? A **mixture** is a combination of two or more pure substances in which each pure substance retains its individual chemical properties. The composition of mixtures is variable, and the number of mixtures that can be created by combining substances is infinite. Although much of the focus of chemistry is the behavior of substances, it is important to remember that most everyday matter occurs as mixtures. Substances tend to mix naturally; it is difficult to keep any substance pure.

Two mixtures are shown in **Figure 3.11.** Although you cannot distinguish between the components of the mercury silver mixture in **Figure 3.11a,** you can separate them by heating the mixture. The mercury will evaporate before the silver does, and you will obtain two separate substances: mercury vapor and solid silver. The mercury and silver physically mixed to form the mixture but did not chemically react with each other. They could be separated by the physical method of boiling. When oil, seasonings, and vinegar are mixed, as shown in **Figure 3.11b,** the substances are in contact, but they do not react. In fact, you can still distinguish all of the substances. If the mixture remains undisturbed long enough, the oil will form a layer on top of the vinegar.

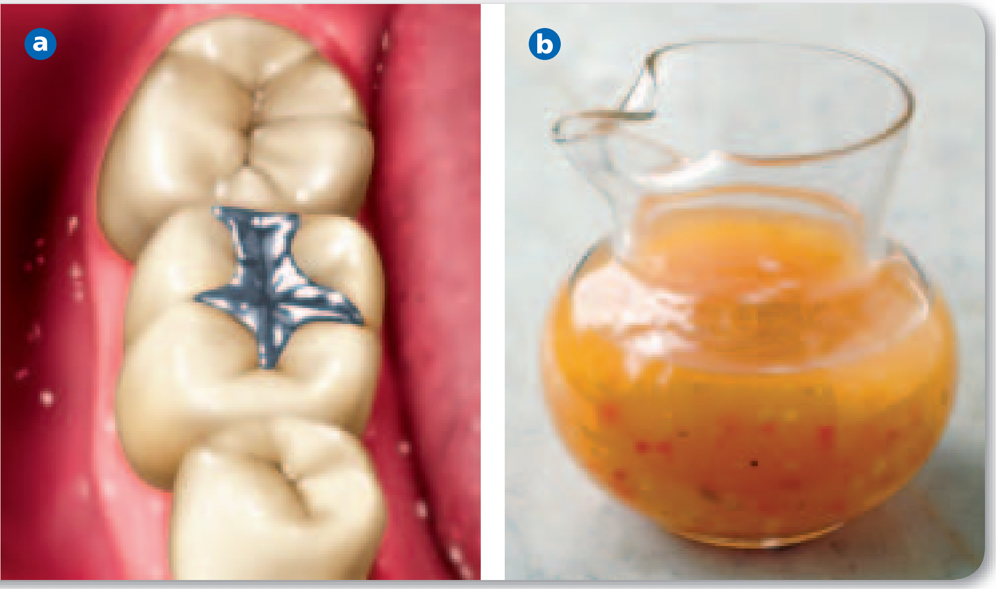


Figure 3.11 There are different types of mixures. **a.** It is not possible to see the different components of some mixtures, such as this mercury-silver filling. **b.** The components of other types of mixtures are visible, as in this salad dressing.

Types of mixtures The combinations of pure substances shown in **Figure 3.11** are both mixtures, despite their obvious visual differences. Mixtures can be defined in different ways and are classified as either heterogeneous or homogeneous.

A **heterogeneous mixture** is a mixture that does not blend smoothly throughout and in which the individual substances remain distinct. The salad dressing mixture is an example of a heterogeneous mixture. Its composition is not uniform—the substances have not blended smoothly and remain distinct. In another example, fresh-squeezed orange juice is a heterogeneous mixture of juice and pulp. The pulp component floats in the juice component. We can therefore say that the existence of two or more distinct areas indicates a heterogeneous mixture.

A **homogeneous mixture** is a mixture that has constant composition throughout; it always has a single phase. If you cut two pieces out of a silver mercury amalgam, their compositions will be the same. They will contain the same relative amounts of silver and mercury, no matter the size of each piece.

Reading Check **Compare and contrast** heterogeneous and homogeneous mixtures. Give examples of each.

Homogeneous mixtures are also referred to as **solutions.** You are probably most familiar with solutions in a liquid form, such as tea and lemonade, but solutions can be solids, liquids, or gases. They can be a mixture of a solid and a gas, a solid and a liquid, a gas and a liquid, and so on. **Table 3.3** lists the various types of solution systems and examples. Each solution system described in the table is also represented in **Figure 3.12.**

The solid-solid solution known as steel is called an alloy. An alloy is a homogeneous mixture of metals, or a mixture of a metal and a nonmetal in which the metal substance is the major component. For instance, steel is a mixture of iron and carbon. Adding carbon atoms increases the hardness of the metal.

Manufacturers combine the properties of various metals in an alloy to achieve greater strength and durability in their products. Jewelry is often made of alloys such as bronze, sterling silver, pewter, and 14-karat gold.

CLICK HERE

Concepts In Motion

Interactive Table Explore solution systems at glencoe.com.

Table 3.3 Types of Solution Systems

System	Example
Gas-gas	Air in a scuba tank is primarily a mixture of nitrogen, oxygen, and argon gases.
Gas-liquid	Oxygen and carbon dioxide are dissolved in seawater.
Liquid-gas	Moist air exhaled by the scuba diver contains water droplets.
Liquid-liquid	When it is raining, fresh water mixes with seawater.
Solid-liquid	Solid salts are dissolved in seawater.
Solid-solid	The air tank is made of an alloy—a mixture of two metals.

Vocabulary

Word origin

Mixture
from the Latin word *misceo,* meaning *to mix* or *blend*

CAREERS IN CHEMISTRY

Materials Scientist Materials scientists synthesize new materials and analyze their properties. They work in national laboratories, in industry, and in academia. For example, scientists at NASA have developed new aluminum-silicon alloys that can be employed to build lighter and stronger engines. To learn more about chemistry careers, visit glencoe.com.

Figure 3.12 All types of solution systems are represented in this photo.

■ **Figure 3.13** As the mixture passes through the filter, the solids remain in the filter, while the filtrate (the remaining liquid) is collected in the beaker.

Separating Mixtures

Most matter exists naturally in the form of mixtures. To gain a thorough understanding of matter, it is important to be able to separate mixtures into their component substances. Because the substances in a mixture are physically combined, the processes used to separate a mixture are physical processes that are based on differences in the physical properties of the substances. For instance, a mixture of iron and sand can be separated into its components with a magnet because a magnet will attract iron but not sand. Numerous techniques have been developed that take advantage of different physical properties in order to separate various mixtures.

Filtration Heterogeneous mixtures composed of solids and liquids are easily separated by filtration. **Filtration** is a technique that uses a porous barrier to separate a solid from a liquid. As **Figure 3.13** shows, the mixture is poured through a piece of filter paper that has been folded into a cone shape. The liquid passes through, leaving the solids trapped in the filter paper.

Distillation Most homogeneous mixtures can be separated by distillation. **Distillation** is a separation technique that is based on differences in the boiling points of the substances involved. In distillation, a mixture is heated until the substance with the lowest boiling point boils to a vapor that can then be condensed into a liquid and collected. When precisely controlled, distillation can separate substances that have boiling points differing by only a few degrees.

MiniLab

Observe Dye Separation

How does paper chromatography allow you to separate substances? Chromatography is an important diagnostic tool used by chemists and forensic technicians to separate and analyze substances.

Procedure

1. Read and complete the lab safety form.
2. Fill a **9-oz wide-mouth plastic cup** with **water** to about 2 cm from the top. Wipe off any water drops on the lip of the cup.
3. Place a piece of **round filter paper** on a clean, dry surface. Make a concentrated ink spot in the center of the paper by firmly pressing the tip of a **black water-soluble pen or marker** onto the paper.
4. Use **scissors** or another sharp object to create a small hole, about the diameter of a pen tip, in the center of the ink spot.
   WARNING: *Sharp objects can puncture skin.*
5. Roll one quarter of an 11-cm round filter paper into a tight cone. This will act as a wick to draw the ink. Work the pointed end of the wick into the hole in the center of the round filter paper.
6. Place the paper/wick apparatus on top of the cup of water, with the wick in the water. The water will move up the wick and outward through the round paper.
7. When the water has moved to within about 1 cm of the edge of the paper (about 20 min), carefully remove the paper from the water-filled cup and put it on a second empty **cup.**

Analysis

1. **Record** the number of distinct dyes you can identify on a drawing of the round filter paper. Label the color bands.
2. **Infer** why you see different colors at different locations on the filter paper.
3. **Compare** your chromatogram with those of your classmates. Explain any differences you might observe.

Crystallization Making rock candy from a sugar solution is an example of separation by crystallization. **Crystallization** is a separation technique that results in the formation of pure solid particles of a substance from a solution containing the dissolved substance. When the solution contains as much dissolved substance as it can possibly hold, the addition of even a tiny amount more often causes the dissolved substance to come out of solution and collect as crystals on any available surface. In the rock candy example, as water evaporates from the sugar-water solution, the solution becomes more concentrated. This is equivalent to adding more of the dissolved substance to the solution. As more water evaporates, the sugar forms a solid crystal on the string, as shown in **Figure 3.14.** Crystallization produces highly pure solids.

Sublimation Mixtures can also be separated by **sublimation,** which is the process during which a solid changes to vapor without melting, i.e. without going through the liquid phase. Sublimation can be used to separate two solids present in a mixture when one of the solids sublimates but not the other.

Chromatography **Chromatography** is a technique that separates the components of a mixture (called the mobile phase) based on the ability of each component to travel or be drawn across the surface of another material (called the stationary phase). Usually, the mobile phase is a gas or a liquid, and the stationary phase is a solid, such as chromatography paper. The separation occurs because the various components of the mixture spread through the paper at different rates. Components with the strongest attraction for the paper travel slower.

Figure 3.14 As the water evaporates from the water-sugar solution, the sugar crystals form on the string.

Section 3.3 Assessment

Section Summary

- A mixture is a physical blend of two or more pure substances in any proportion.
- Solutions are homogeneous mixtures.
- Mixtures can be separated by physical means. Common separation techniques include filtration, distillation, crystallization, sublimation, and chromatography.

15. MAIN Idea **Classify** each of the following as either a heterogeneous or a homogeneous mixture.
    a. tap water **b.** air **c.** raisin muffin
16. **Compare** mixtures and substances.
17. **Describe** the separation technique that could be used to separate each of the following mixtures.
    a. two colorless liquids
    b. a nondissolving solid mixed with a liquid
    c. red and blue marbles of the same size and mass
18. **Design** a concept map that summarizes the relationships among matter, elements, mixtures, compounds, pure substances, homogeneous mixtures, and heterogeneous mixtures.

Section 3.4

Objectives

- **Distinguish** between elements and compounds.
- **Describe** the organization of elements in the periodic table.
- **Explain** how all compounds obey the laws of definite and multiple proportions.

Review Vocabulary

proportion: the relation of one part to another or to the whole with respect to quantity

New Vocabulary

element
periodic table
compound
law of definite proportions
percent by mass
law of multiple proportions

Elements and Compounds

MAIN Idea **A compound is a combination of two or more elements.**

Real-World Reading Link When you eat fruit salad, you can eat each piece of fruit separately. However, when you eat jelly, you cannot separate each piece of fruit from the others. The same way jelly is made up of fruits, compounds are made up of elements. You cannot see individual elements in the compounds.

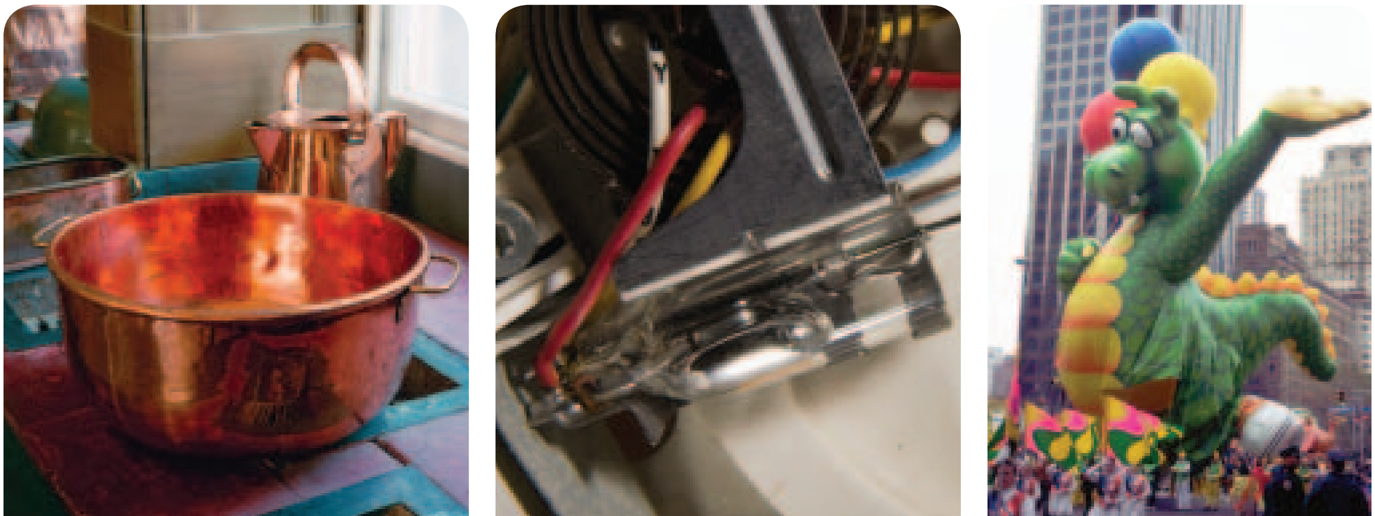
Elements

Earlier in this chapter, you considered the diversity of your surroundings in terms of matter. Although matter can take many different forms, all matter can be broken down into a relatively small number of basic building blocks called elements. An **element** is a pure substance that cannot be separated into simpler substances by physical or chemical means. On Earth, 92 elements occur naturally. Copper, oxygen, and gold are examples of naturally occurring elements. There are also several elements that do not exist naturally but have been developed by scientists.

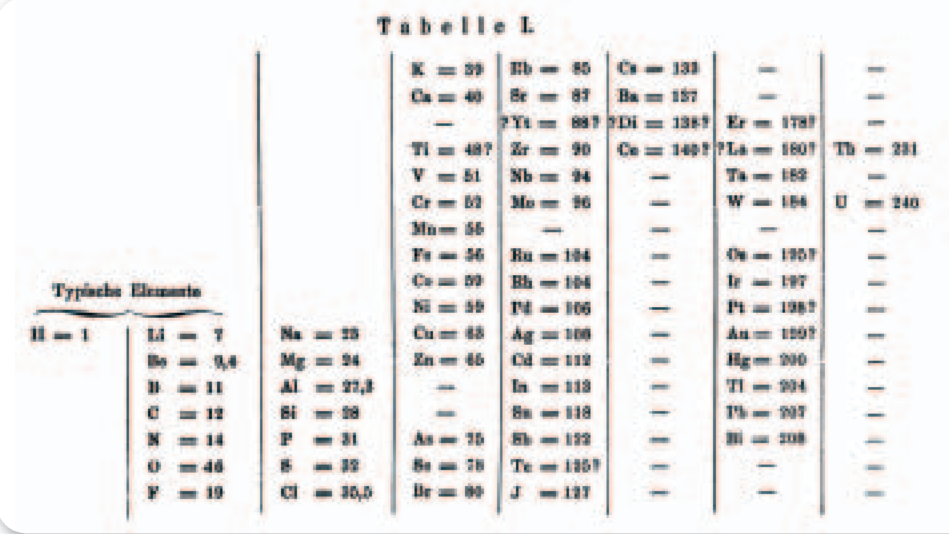
Each element has a unique chemical name and symbol. The chemical symbol consists of one, two, or three letters; the first letter is always capitalized, and the remaining letter(s) are always lowercase. The names and symbols of the elements are universally accepted by scientists in order to make the communication of chemical information possible.

The 92 naturally occurring elements are not equally abundant. For example, hydrogen is estimated to make up approximately 75% of the mass of the universe. Oxygen and silicon together comprise almost 75% of the mass of Earth's crust, while oxygen, carbon, and hydrogen account for more than 90% of the human body. Francium, on the other hand, is one of the least-abundant naturally-occurring elements. There is probably less than 20 g of francium dispersed throughout Earth's crust. Elements are found in different physical states in normal conditions, as shown in **Figure 3.15.**

■ **Figure 3.15** In normal conditions, elements exist in different states.



Copper pot—solid | **Mercury switch—liquid** | **Helium balloon—gas**



■ **Figure 3.16** Mendeleev was one of the first scientists to organize elements in a periodic manner, as shown in this chart, and to observe periodic patterns in the properties of the elements.

A first look at the periodic table As many new elements were being discovered in the early nineteenth century, chemists began to observe and study patterns of similarities in the chemical and physical properties of particular sets of elements. In 1869, Russian chemist Dmitri Mendeleev (1834–1907) devised a chart, shown in **Figure 3.16,** which organized all of the elements that were known at the time. His classification was based on the similarities and masses of the elements. Mendeleev's table was the first version of what has been further developed into the periodic table of the elements. The **periodic table** organizes the elements into a grid of horizontal rows called periods and vertical columns called groups or families. Elements in the same group have similar chemical and physical properties. The table is called periodic because the pattern of similar properties repeats from period to period. The periodic table can be found at the end of this book and will be examined in greater detail in Chapter 6.

Compounds

Many pure substances can be classified as compounds. A **compound** is made up of two or more different elements that are combined chemically. Most matter in the universe exists in the form of compounds.

Today, there are approximately 10 million known compounds, and new compounds continue to be developed and discovered at the rate of about 100,000 per year. There appears to be no limit to the number of compounds that can be made or that will be discovered. Considering this virtually limitless potential, several organizations have assumed the task of collecting data and indexing the known chemical compounds. The information is stored in databases.

Reading Check **Define** *element* and *compound.*

The chemical symbols of the periodic table make it easy to write the formulas for chemical compounds. For example, table salt, which is called sodium chloride, is composed of one part sodium (Na) and one part chlorine (Cl), and its chemical formula is NaCl. Water is composed of two parts hydrogen (H) and one part oxygen (O), and its chemical formula is H_2O. The subscript 2 indicates that two hydrogen elements combine with one oxygen element to form water.

Vocabulary

Science usage v. Common usage

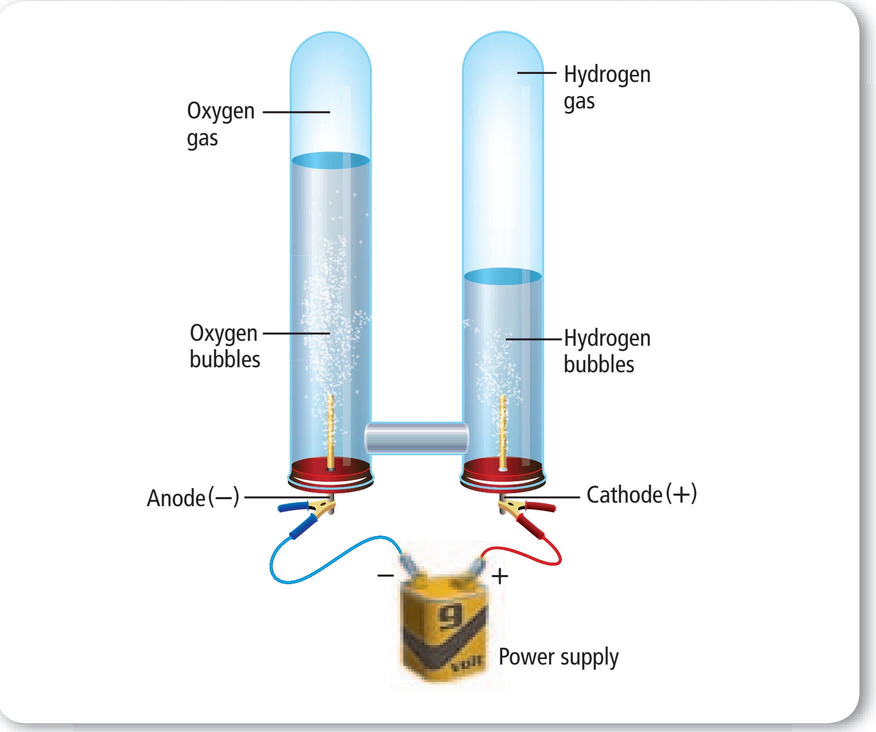
Element

Science usage: a pure substance that cannot be separated into simpler substances by ordinary chemical means
Lead is one of the heaviest elements.

Common usage: the state or sphere that is natural or suited to any person or thing
In snow, huskies are in their element.

■ **Figure 3.17** An electric current breaks down water into its components, oxygen and hydrogen.

Determine ***What is the ratio between the amount of hydrogen and the amount of oxygen released during electrolysis?***

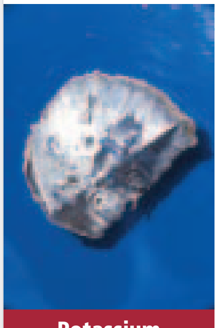


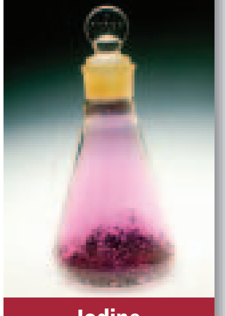
Separating compounds into components As you have read earlier in this chapter, elements can never be separated into simpler substances. However, compounds can be broken down into simpler substances by chemical means. In general, compounds that occur naturally are more stable than the individual component elements. Separating a compound into its elements often requires external energy, such as heat or electricity. **Figure 3.17** shows the setup used to produce the chemical change of water into its component elements—hydrogen and oxygen—through a process called electrolysis. During electrolysis, one end of a long platinum electrode is exposed to the water in a tube and the other end is attached to a power source. An electric current splits water into hydrogen gas in the compartment on the right and oxygen gas in the compartment on the left. Because water is composed of two parts hydrogen and one part oxygen, there is twice as much hydrogen gas than oxygen gas.

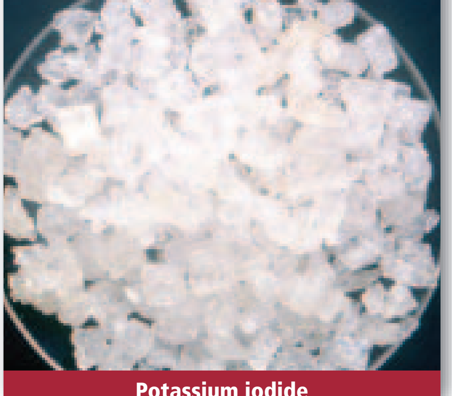
Reading Check **Explain** the process of electrolysis.

Properties of compounds The properties of a compound are different from those of its component elements. The example of water in **Figure 3.17** illustrates this fact. Water is a stable compound that is liquid at room temperature. When water is broken down, its components, hydrogen and oxygen, are dramatically different than the liquid they form when combined. Oxygen and hydrogen are colorless, odorless gases that undergo vigorous chemical reactions with many elements. This difference in properties is a result of a chemical reaction between the elements. **Figure 3.18** shows the component elements—potassium and iodine—of the compound called potassium iodide. Note how different the properties of potassium iodide are from its component elements. Potassium is a light silver metal that reacts with water. Iodine is a black solid that changes into a purple gas at room temperature. Potassium iodide is a white salt.

■ **Figure 3.18** When potassium and iodine react, they form potassium iodide, a compound with different properties.


Potassium


Iodine


Potassium iodide

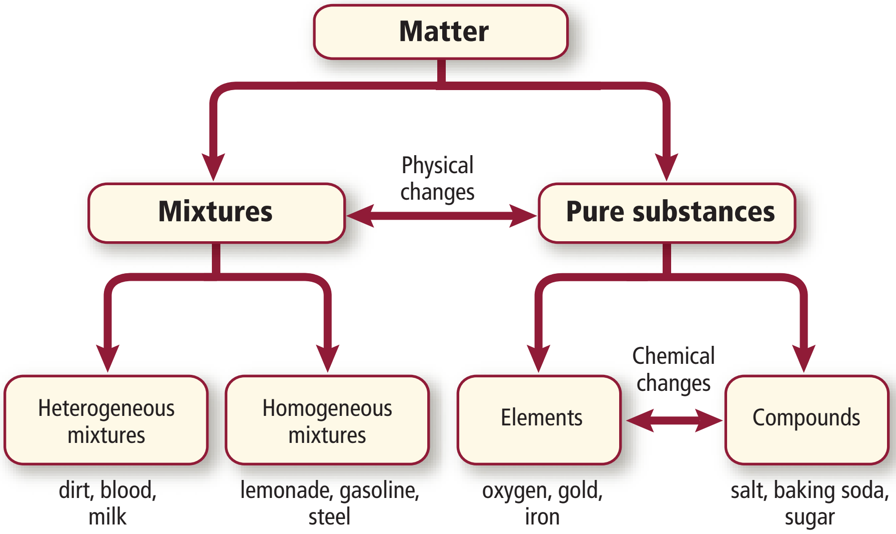


Figure 3.19 Matter can be classified into different categories that have defined properties.
Examine ***How are mixtures and substances related? Elements and compounds?***

Recall what you have read about the organization of matter. You know that matter is classified as pure substances and mixtures. As you learned in the previous section, a mixture can be homogeneous or heterogeneous. You also know that an element is a pure substance that cannot be separated into simpler substances, whereas a compound is a chemical combination of two or more elements and can be separated into its components. Use **Figure 3.19** to review the classification of matter and how its components are related to each other.

Reading Check **Summarize** the different types of matter and how they are related to each other.

Law of Definite Proportions

An important characteristic of compounds is that the elements comprising them always combine in definite proportions by mass. This observation is so fundamental that it is summarized as the law of definite proportions. The **law of definite proportions** states that a compound is always composed of the same elements in the same proportion by mass, no matter how large or small the sample. The mass of the compound is equal to the sum of the masses of the elements that make up the compound.

The relative amounts of the elements in a compound can be expressed as percent by mass. The **percent by mass** is the ratio of the mass of each element to the total mass of the compound expressed as a percentage.

Percent by Mass

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

Percent by mass is obtained by dividing the mass of the element by the mass of the compound and then by multiplying this ratio by 100 to express it as a percentage.

Reading Check **State** the law of definite proportions.

Table 3.4 Sucrose Analysis

	20.00 g of Granulated Sugar		500.0 g of Sugarcane	
Element	Analysis by Mass (g)	Percent by Mass (%)	Analysis by Mass (g)	Percent by Mass (%)
Carbon	8.44	$\frac{8.44 \text{ g C}}{20.00 \text{ g sucrose}} \times 100 = 42.20\%$	211.0	$\frac{211.0 \text{ g C}}{500.00 \text{ g sucrose}} \times 100 = 42.20\%$
Hydrogen	1.30	$\frac{1.30 \text{ g H}}{0.00 \text{ g sucrose}} \times 100 = 6.50\%$	32.5	$\frac{32.50 \text{ g H}}{500.00 \text{ g sucrose}} \times 100 = 6.50\%$
Oxygen	10.26	$\frac{10.26 \text{ g O}}{20.00 \text{ g sucrose}} \times 100 = 51.30\%$	256.5	$\frac{256.5 \text{ g O}}{500.00 \text{ g sucrose}} \times 100 = 51.30\%$
Total	20.00	100%	500.0	100%

ChemistryOnline

Personal Tutor For an online tutorial on percentages, visit glencoe.com.

For example, consider the compound granulated sugar (sucrose). This compound is composed of three elements—carbon, hydrogen, and oxygen. The analysis of 20.00 g of sucrose from a bag of granulated sugar is given in **Table 3.4.** Note that the sum of the individual masses of the elements found in the sugar equals 20.00 g, which is the amount of the granulated sugar sample that was analyzed. This demonstrates the law of conservation of mass as applied to compounds: the mass of a compound is equal to the sum of the masses of the elements that make up the compound.

Suppose you analyzed 500.0 g of sucrose from a sample of sugarcane. The analysis is shown in **Table 3.4.** The percent-by-mass values for the sugarcane are equal to the values obtained for the granulated sugar. According to the law of definite proportions, samples of a compound from any source must have the same mass proportions. Conversely, compounds with different mass proportions must be different compounds. Thus, you can conclude that samples of sucrose will always be composed of 42.20% carbon, 6.50% hydrogen, and 51.30% oxygen, no matter their sources.

PRACTICE Problems

Extra Practice Page 977 and glencoe.com

19. A 78.0-g sample of an unknown compound contains 12.4 g of hydrogen. What is the percent by mass of hydrogen in the compound?

20. 1.0 g of hydrogen reacts completely with 19.0 g of fluorine. What is the percent by mass of hydrogen in the compound that is formed?

21. If 3.5 g of element X reacts with 10.5 g of element Y to form the compound XY, what is the percent by mass of element X in the compound? The percent by mass of element Y?

22. Two unknown compounds are tested. Compound I contains 15.0 g of hydrogen and 120.0 g of oxygen. Compound II contains 2.0 g of hydrogen and 32.0 g of oxygen. Are the compounds the same? Explain your answer.

23. **Challenge** All you know about two unknown compounds is that they have the same percent by mass of carbon. With only this information, can you be sure the two compounds are the same? Explain.

Law of Multiple Proportions

Compounds composed of different elements are obviously different compounds. However, different compounds can also be composed of the same elements. This happens when those different compounds have different mass compositions. The **law of multiple proportions** states that when different compounds are formed by a combination of the same elements, different masses of one element combine with the same relative mass of the other element in a ratio of small whole numbers. Ratios compare the relative amounts of any items or substances. The comparison can be expressed using numbers separated by a colon or as a fraction. With regard to the law of multiple proportions, ratios express the relationship of elements in a compound.

Reading Check **State** the law of multiple proportions in your own words.

Water and hydrogen peroxide The two distinct compounds water (H_2O) and hydrogen peroxide (H_2O_2) illustrate the law of multiple proportions. Each compound contains the same elements (hydrogen and oxygen). Water is composed of two parts hydrogen and one part oxygen. Hydrogen peroxide is composed of two parts hydrogen and two parts oxygen. Hydrogen peroxide differs from water in that it has twice as much oxygen. When you compare the mass of oxygen in hydrogen peroxide to the mass of oxygen in water, you get the ratio 2:1.

Compounds made of copper and chlorine In another example, copper (Cu) reacts with chlorine (Cl) under different sets of conditions to form two different compounds. **Table 3.5** provides an analysis of their compositions. The two copper compounds must be different because they have different percents by mass. Compound I contains 64.20% copper; Compound II contains 47.27% copper. Compound I contains 35.80% chlorine; Compound II contains 52.73% chlorine.

Using **Figure 3.20** and **Table 3.5,** compare the ratio of the mass of copper to the mass of chlorine for each compound. Notice that the mass ratio of copper to chlorine in Compound I (1.793) is exactly 2 times the mass ratio of copper to chlorine in Compound II (0.8964).

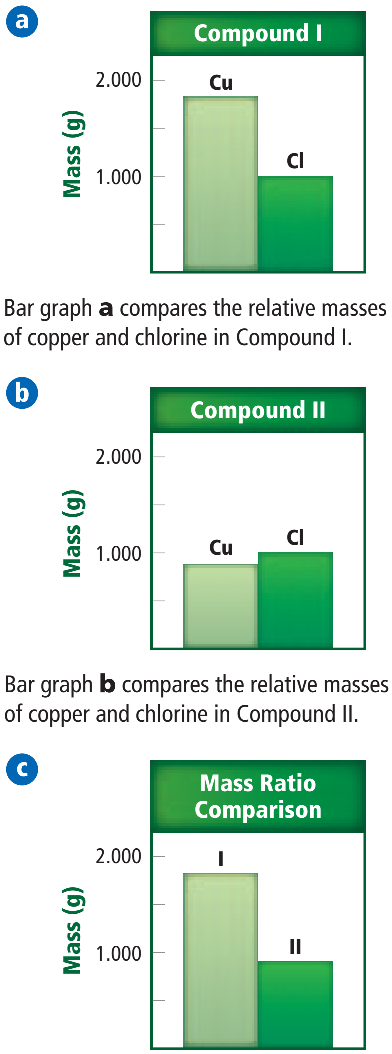
$$\frac{\text{mass ratio of Compound I}}{\text{mass ratio of Compound II}} = \frac{1.793 \text{ g Cu/g Cl}}{0.8964 \text{ g Cu/g Cl}} = 2.000$$

Graph Check **Explain** why the ratio of the relative masses of copper in both compounds is 2:1.

Table 3.5 Analysis Data of Two Copper Compounds

Compound	% Cu	% Cl	Mass Cu (g) in 100.0 g of Compound	Mass Cl (g) in 100.0 g of Compound	Mass Ratio $\left(\frac{\text{mass Cu}}{\text{mass Cl}}\right)$
I	64.20	35.80	64.20	35.80	1.793 g Cu/1 g Cl
II	47.27	52.73	47.27	52.73	0.8964 g Cu/1 g Cl

Figure 3.20 Copper and chlorine can form different compounds.



Bar graph **c** shows a comparison between the relative masses of copper in both compounds. The ratio is 2:1.

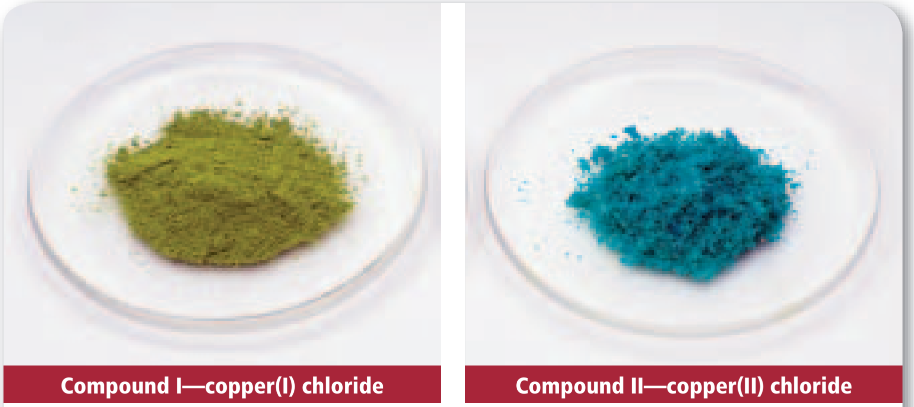


Figure 3.21 Different compounds are formed when different relative masses of each element are combined. Although they are both made of copper and chlorine, Compound I has a greenish color, whereas Compound II has a bluish color

Figure 3.21 shows the two compounds formed by the combination of copper and chlorine and presented in **Table 3.5** and **Figure 3.20.** These compounds are called copper (I) chloride and copper (II) chloride. As the law of multiple proportions states, the different masses of copper that combine with a fixed mass of chlorine in the two different copper compounds, can be expressed as a small whole-number ratio. In this case, the ratio is 2:1.

Considering that there is a finite number of elements that exist today and an exponentially greater number of compounds that are composed of these elements under various conditions, it becomes clear how important the law of multiple proportions is in chemistry.

Section 3.4 Assessment

Section Summary

- Elements cannot be broken down into simpler substances.
- Elements are organized in the periodic table of the elements.
- Compounds are chemical combinations of two or more elements, and their properties differ from the properties of their component elements.
- The law of definite proportions states that a compound is always composed of the same elements in the same proportions.
- The law of multiple proportions states that if elements form more than one compound, those compounds will have compositions that are whole-number multiples of each other.

24. MAIN Idea **Compare and contrast** elements and compounds.
25. **Describe** the basic organizational feature of the periodic table of the elements.
26. **Explain** how the law of definite proportions applies to compounds.
27. **State** the type of compounds that are compared in the law of multiple proportions.
28. **Complete** the table, and then analyze the data to determine if Compounds I and II are the same compound. If the compounds are different, use the law of multiple proportions to show the relationship between them.

Analysis Data of Two Iron Compounds

Compound	Total Mass (g)	Mass Fe (g)	Mass O (g)	Mass Percent Fe	Mass Percent O
I	75.00	52.46	22.54		
II	56.00	43.53	12.47		

29. **Calculate** the mass percent of hydrogen in water and the mass percent of oxygen in water.
30. **Graph** Create a graph that illustrates the law of multiple proportions.

In the Field

Career: Arson Investigator

Forensic Accelerant Detection

Inside a burning warehouse, havoc and destruction reign. Intense heat and smoke fill closed spaces. Leaping flames spread; walls and ceilings collapse. Was the fire accidental or the work of an arsonist?

Accelerants Fire investigators analyze evidence to determine how a fire began and spread. If arson is suspected, it is likely that accelerants—chemicals that speed the spread of a fire—were involved.

The properties of an accelerant The properties that make accelerants useful as fuels also make them dangerous in fire situations. Accelerants are readily absorbed and are powerful solvents. They do not mix well with water, often floating on top. At room temperature, accelerants form vapors that can ignite and burn.

Evidence of an accelerant What evidence indicates the presence of an accelerant? One indicator is an unusual burn pattern, like that present on the floor joists in **Figure 1.** In this case, called a "rundown" burn pattern, an ignitable liquid was likely poured in this area, running down between the floorboards to the joists below.

Figure 1 Accelerants can cause a rundown burn pattern.

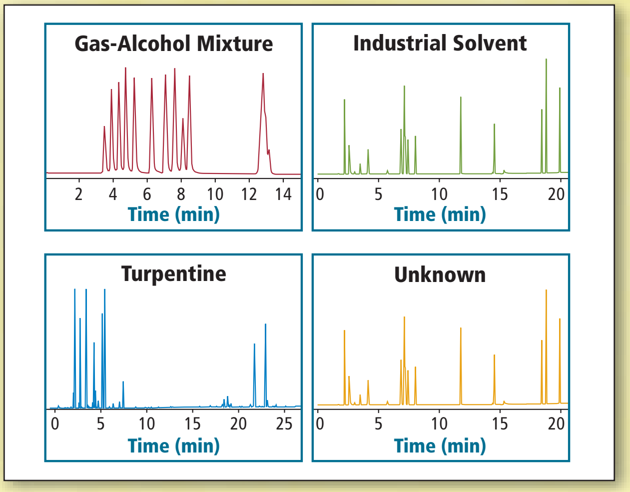


Figure 2 Chromatograms, like fingerprints, are unique.

Another indicator is a small slick on top of any wet material, similar to the automobile-oil slick floating on a puddle on a wet street. If investigators see such clues, they can take samples of the affected materials for testing.

Chemical analysis Investigators take any samples they collect to the lab for chemical analysis. In the lab, a sample is separated using a process called gas chromatography. The components of the mixture are displayed in a chromatogram, like the ones shown in **Figure 2,** for an alcohol-gasoline blend, turpentine, and an industrial solvent. Like fingerprints, chromatograms are unique. By comparing the chromatogram of the unknown with those of known compounds, the identity of the accelerant can be determined.

WRITING in Chemistry

Think Critically Look at the chromatogram of the unknown sample and compare it to the three known samples. Can you determine which accelerant was used? Could that knowledge give you any insight into who might have committed the crime? Explain your answer. Visit glencoe.com to learn more about gas chromatography.

CHEMLAB

IDENTIFY THE PRODUCTS OF A CHEMICAL REACTION

Background: Chemical changes can be studied by observing chemical reactions. Products of the reaction can be identified using a flame test.

Question: *Is there a chemical reaction between copper and silver nitrate? Which elements react, and what is the compound they form?*

Materials

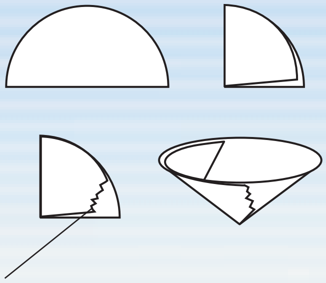
$AgNO_3$ solution
sandpaper
stirring rod
funnel
filter paper
50-mL beaker
50-mL graduated cylinder
250-mL Erlenmeyer flask
small iron ring
ring stand
plastic petri dish
Bunsen burner
tongs
paper clip
copper wire

Safety Precautions

WARNING: ***Silver nitrate is highly toxic. Avoid contact with eyes and skin.***

Procedure

1. Read and complete the lab safety form.
2. Rub 8 cm of copper wire with sandpaper until it is shiny. Observe and record its physical properties.
3. Measure 25 mL $AgNO_3$ (silver nitrate) solution into a 50-mL beaker. Record its physical properties.
4. Coil the copper wire so that it fits into the beaker. Make a hook and suspend it from the stirring rod.
5. Place the stirring rod across the top of the beaker, immersing part of the coil in the $AgNO_3$ solution.
6. Make and record observations of the wire and the solution every 5 min for 20 min.
7. Set up a filtration apparatus: attach the iron ring to the ring stand, and adjust its height so the end of the funnel is inside the neck of the Erlenmeyer flask.
8. Fold the circle filter paper in half twice to form a quarter of a circle. Tear off the lower-right corner of the flap facing you. Open the folded paper into a cone, and place it into the funnel.
9. Remove the coil from the beaker, and dispose of it as directed by your teacher.



10. Slowly pour the liquid down the stirring rod into the funnel to catch the solid products in the filter paper.
11. Collect the filtrate in the Erlenmeyer flask, and transfer it to a petri dish.
12. Adjust a Bunsen burner flame until it is blue. Hold the paper clip in the flame with tongs until no additional color is observed.
13. Using tongs, dip the hot paper clip into the filtrate. Then, hold the paper clip in the flame. Record the color you observe. After removing the clip from the burner, let it cool before handling.
14. **Cleanup and Disposal** Dispose of materials as directed by your teacher. Clean and return all lab equipment to its proper place.

Analyze and Conclude

1. **Observe and Infer** Describe the changes you observed in Step 6. Is there evidence that a chemical change occurred? Predict the products formed.
2. **Compare** Use resources such as the *CRC Handbook of Chemistry and Physics* to determine the colors of silver metal and copper nitrate in water. Compare this information with your observations of the reactants and products in Step 6.
3. **Identify** Copper emits a blue-green light in flame tests. Do your observations confirm the presence of copper in the filtrate collected in Step 11?
4. **Classify** Which type of mixture is silver nitrate in water? Which type of mixture is formed after Step 6?

INQUIRY EXTENSION

Compare your recorded observations with those of several other lab teams. Form a hypothesis to explain any differences; design an experiment to test it.

Study Guide

STUDY TO GO Download quizzes, key terms, and flash cards from glencoe.com.

BIG Idea Everything is made of matter.

Section 3.1 Properties of Matter

MAIN Idea Most common substances exist as solids, liquids, and gases, which have diverse physical and chemical properties.

Vocabulary

- chemical property (p. 74)
- extensive property (p. 73)
- gas (p. 72)
- intensive property (p. 73)
- liquid (p. 71)
- physical property (p. 73)
- solid (p. 71)
- states of matter (p. 71)
- vapor (p. 72)

Key Concepts

- The three common states of matter are solid, liquid, and gas.
- Physical properties can be observed without altering a substance's composition.
- Chemical properties describe a substance's ability to combine with or change into one or more new substances.
- External conditions can affect both physical and chemical properties.

Section 3.2 Changes in Matter

MAIN Idea Matter can undergo physical and chemical changes.

Vocabulary

- chemical change (p. 77)
- law of conservation of mass (p. 77)
- phase change (p. 76)
- physical change (p. 76)

Key Concepts

- A physical change alters the physical properties of a substance without changing its composition.
- A chemical change, also known as a chemical reaction, involves a change in a substance's composition.
- In a chemical reaction, reactants form products.
- The law of conservation of mass states that mass is neither created nor destroyed during a chemical reaction; it is conserved.

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

Section 3.3 Mixtures of Matter

MAIN Idea Most everyday matter occurs as mixtures—combinations of two or more substances.

Vocabulary

- chromatography (p. 83)
- crystallization (p. 83)
- distillation (p. 82)
- filtration (p. 82)
- heterogeneous mixture (p. 81)
- homogeneous mixture (p. 81)
- mixture (p. 80)
- solution (p. 81)
- sublimation (p. 83)

Key Concepts

- A mixture is a physical blend of two or more pure substances in any proportion.
- Solutions are homogeneous mixtures.
- Mixtures can be separated by physical means. Common separation techniques include filtration, distillation, crystallization, sublimation, and chromatography.

Section 3.4 Elements and Compounds

MAIN Idea A compound is a combination of two or more elements.

Vocabulary

- compound (p. 85)
- element (p. 84)
- law of definite proportions (p. 87)
- law of multiple proportions (p. 89)
- percent by mass (p. 87)
- periodic table (p. 85)

Key Concepts

- Elements cannot be broken down into simpler substances.
- Elements are organized in the periodic table of the elements.
- Compounds are chemical combinations of two or more elements and their properties differ from the properties of their component elements.
- The law of definite proportions states that a compound is always composed of the same elements in the same proportions.

$$\text{percent by mass} = \frac{\text{mass of the element}}{\text{mass of the compound}} \times 100$$

- The law of multiple proportions states that if elements form more than one compound, those compounds will have compositions that are whole-number multiples of each other.

Chemistry Online Vocabulary PuzzleMaker glencoe.com

CHAPTER 3 Assessment

Section 3.1

Mastering Concepts

31. List three examples of substances. Explain why each is a substance.

32. Is carbon dioxide gas a pure substance? Explain.

33. List at least three physical properties of water.

34. Identify each physical property as extensive or intensive.
a. melting point
b. mass
c. density
d. length

35. "Properties are not affected by changes in temperature and pressure." Is this statement true or false? Explain.

36. List the three states of matter, and give an example for each state. Differentiate between a gas and a vapor.

37. Classify each as either a solid, a liquid, or a gas at room temperature.
a. milk
b. air
c. copper
d. helium
e. diamond
f. candle wax

38. Classify each as a physical property or a chemical property.
a. Aluminum has a silvery color.
b. Gold has a density of 19 g/cm^3.
c. Sodium ignites when dropped in water.
d. Water boils at 100°C.
e. Silver tarnishes.
f. Mercury is a liquid at room temperature.

39. A carton of milk is poured into a bowl. Describe the changes that occur in the milk's shape and volume.

40. **Boiling Water** At what temperature would 250 mL of water boil? 1000 mL? Is the boiling point an intensive or extensive property? Explain.

Mastering Problems

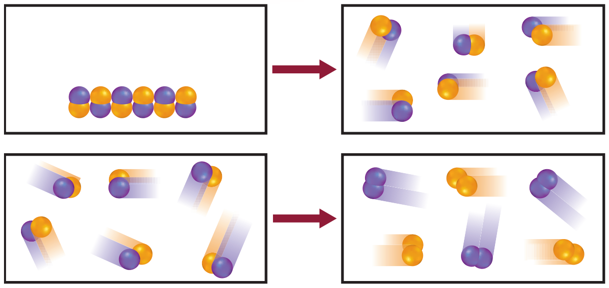
41. **Chemical Analysis** A scientist wants to identify an unknown compound on the basis of its physical properties. The substance is a white solid at room temperature. Attempts to determine its boiling point were unsuccessful. Using **Table 3.6**, name the unknown compound.

Table 3.6 Physical Properties of Common Substances

Substance	Color	State at 25°C	Boiling Point (°C)
Oxygen	colorless	gas	−183
Water	colorless	liquid	100
Sucrose	white	solid	decomposes
Sodium chloride	white	solid	1413

Section 3.2

Mastering Concepts



■ **Figure 3.22**

42. Label each set of diagrams in **Figure 3.22** as a physical or a chemical change.

43. Classify each as a physical change or a chemical change.
a. breaking a pencil in two
b. water freezing and forming ice
c. frying an egg
d. burning wood
e. leaves changing colors in the fall

44. **Ripening** Is the process of bananas ripening a chemical change or a physical change? Explain.

45. Is a change in phase a physical change or a chemical change? Explain.

46. List four indicators that a chemical change has probably occured.

47. **Rust** Iron and oxygen combine to form iron oxide, or rust. List the reactants and products of this reaction.

48. **Burning Candle** After burning for three hours, a candle has lost half of its mass. Explain why this example does not violate the law of conservation of mass.

49. Describe the difference between a physical change and a chemical change.

Mastering Problems

50. **Ammonia Production** A 28.0-g sample of nitrogen gas combines completely with 6.0 g of hydrogen gas to form ammonia. What is the mass of ammonia formed?

51. A 13.0-g sample of X combines with a 34.0-g sample of Y to form the compound XY_2. What is the mass of the reactants?

52. If 45.98 g of sodium combines with an excess of chlorine gas to form 116.89 g of sodium chloride, what mass of chlorine gas is used in the reaction?

53. A substance breaks down into its component elements when it is heated. If 68.0 g of the substance is present before it is heated, what is the combined mass of the component elements after heating?

Chemistry Online **Chapter Test** glencoe.com

54. Copper sulfide is formed when copper and sulfur are heated together. In this reaction, 127 g of copper reacts with 41 g of sulfur. After the reaction is complete, 9 g of sulfur remains unreacted. What is the mass of copper sulfide formed?

55. When burning 180 g of glucose in the presence of 192 g of oxygen, water and carbon dioxide are produced. If 108 g of water is produced, how much carbon dioxide is produced?

Section 3.3

Mastering Concepts

56. Describe the characteristics of a mixture.

■ **Figure 3.23**

57. Name the separation method illustrated in **Figure 3.23**.

58. Describe a method that could be used to separate each mixture.
   - **a.** iron filings and sand
   - **b.** sand and salt
   - **c.** the components of ink
   - **d.** helium and oxygen gases

59. "A mixture is the chemical bonding of two or more substances in any proportion." Is this statement true or false? Explain.

60. Which of the following are the same and which are different?
   - **a.** a substance and a pure substance
   - **b.** a heterogeneous mixture and a solution
   - **c.** a substance and a mixture
   - **d.** a homogeneous mixture and a solution

61. Describe how a homogeneous mixture differs from a heterogeneous mixture.

62. **Seawater** is composed of salt, sand, and water. Is seawater a heterogeneous or homogeneous mixture? Explain.

63. **Iced Tea** Use iced tea with and without ice cubes as examples to explain homogeneous and heterogeneous mixtures. If you allow all of the ice cubes to melt, what type of mixture remains?

64. **Chromatography** What is chromatography, and how does it work?

Section 3.4

Mastering Concepts

65. State the definition of element.

66. Correct the following statements.
   - **a.** An element is a combination of two or more compounds.
   - **b.** When a small amount of sugar is completely dissolved in water, a heterogeneous solution is formed.

67. Name the elements contained in the following compounds.
   - **a.** sodium chloride (NaCl)
   - **b.** ammonia (NH_3)
   - **c.** ethanol (C_2H_6O)
   - **d.** bromine (Br_2)

68. What was Dmitri Mendeleev's major contribution to the field of chemistry?

69. Is it possible to distinguish between an element and a compound? Explain.

70. How are the properties of a compound related to those of the elements that comprise it?

71. Which law states that a compound always contains the same elements in the same proportion by mass?

72. **a.** What is the percent by mass of carbon in 44 g of carbon dioxide (CO_2)?
   b. What is the percent by mass of oxygen in 44 g of carbon dioxide (CO_2)?

73. Complete **Table 3.7** by classifying the compounds as 1:1 or 2:2, 1:2 or 2:1, and 1:3 or 3:1.

Table 3.7 Ratios of Elements in Compounds

Compound	Simple Whole-Number Ratios of Elements
NaCl	
CuO	
H_2O	
H_2O_2	

Mastering Problems

74. A 25.3-g sample of an unknown compound contains 0.8 g of oxygen. What is the percent by mass of oxygen in the compound?

75. Magnesium combines with oxygen to form magnesium oxide. If 10.57 g of magnesium reacts completely with 6.96 g of oxygen, what is the percent by mass of oxygen in magnesium oxide?

76. When mercury oxide is heated, it decomposes into mercury and oxygen. If 28.4 g of mercury oxide decomposes, producing 2.0 g of oxygen, what is the percent by mass of mercury in mercury oxide?

77. Carbon reacts with oxygen to form two different compounds. Compound I contains 4.82 g of carbon for every 6.44 g of oxygen. Compound II contains 20.13 g of carbon for every 53.7 g of oxygen. What is the ratio of carbon to a fixed mass of oxygen for the two compounds?

78. A 100-g sample of an unknown salt contains 64 g of chlorine. What is the percent by mass of chlorine in the compound?

79. Which law would you use to compare CO and CO_2? Explain. Without doing any calculations, determine which of the two compounds has the highest percent by mass of oxygen in the compound.

80. Complete **Table 3.8.**

Table 3.8 Elements in Compounds

Compound	Mass of Compound (g)	Mass of Oxygen (g)	Mass % of Oxygen	Mass of Second Element in the Compound (g)
CuO	84.0	16		
H_2O	18.0	16		
H_2O_2	34.0	32		
CO	28.0	16		
CO_2	44.0	32		

Mixed Review

81. Which state(s) of matter are compressible? Which state(s) of matter are not compressible? Explain.

82. Classify each mixture as homogeneous or heterogeneous.
- **a.** brass (an alloy of zinc and copper)
- **b.** a salad
- **c.** blood
- **d.** powdered drink mix dissolved in water

83. Phosphorus combines with hydrogen to form phosphine. In this reaction, 123.9 g of phosphorus combines with excess hydrogen to produce 129.9 g of phosphine. After the reaction, 310 g of hydrogen remains unreacted. What mass of hydrogen is used in the reaction? What was the initial mass of hydrogen before the reaction?

84. If you have 100 particles of hydrogen and 100 particles of oxygen, how many units of water can you form? Will you use all the particles of both elements? If not, what will remain?

85. Classify each substance as a pure substance, a homogeneous mixture, or a heterogeneous mixture.
- **a.** air
- **b.** aerosol
- **c.** soil
- **d.** water
- **e.** sediment
- **f.** muddy water

86. Identify each as a homogenous mixture, a heterogeneous mixture, a compound, or an element.
- **a.** pure drinking water
- **b.** salty water
- **c.** helium
- **d.** seawater
- **e.** air

87. Cooking List physical properties of eggs before and after they are cooked. Based on your observations, does a physical change or chemical change occur when eggs are cooked? Justify your answer.

88. Ice Cream You might have noticed that while eating ice cream on a hot day, some of the ice cream begins to melt. Is the observed change in the state of the ice cream a physical or a chemical change? Justify your answer.

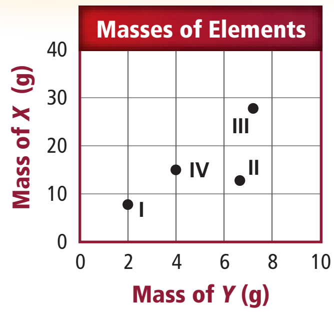
89. Iced Tea Is a mixture of tea and ice homogeneous or heterogeneous? Does that change as the ice melts?

90. Sodium reacts chemically with chlorine to form sodium chloride. Is sodium chloride a mixture or a compound?

91. Is air a solution or a heterogeneous mixture? What technique can be used to separate air into its components?

92. Indicate whether combining the following elements yields a compound or a mixture,
- **a.** $H_2(g) + O_2(g) \longrightarrow$ water
- **b.** $N_2(g) + O_2(g) \longrightarrow$ air

Think Critically



■ **Figure 3.24**

93. Interpret Data A compound contains the elements *X* and *Y*. Four samples with different masses were analyzed, and the masses of *X* and *Y* in each sample were plotted on a graph shown in **Figure 3.24.** The samples were labeled I, II, III, and IV.
- **a.** Which samples are from the same compound? How do you know?
- **b.** What is the approximate ratio of the mass of *X* to the mass of *Y* in the samples that are from the same compound?
- **c.** What is the approximate ratio of the mass of *X* to the mass of *Y* in the sample(s) that are not from the same compound?

94. Apply Air is a mixture of many gases, primarily nitrogen, oxygen, and argon. Could distillation be used to separate air into its component gases? Explain.

95. Analyze Is gas escaping from an opened soft drink an example of a chemical or a physical change? Explain.

96. Apply Give examples of heterogeneous mixtures for the systems listed in **Table 3.9.**

Table 3.9 Heterogeneous Mixtures

System	Example
Liquid-liquid	
Solid-liquid	
Solid-solid	

Challenge Problem

97. Identify Lead Compounds A sample of a certain lead compound contains 6.46 g of lead for each gram of oxygen. A second sample has a mass of 68.54 g and contains 28.76 g of oxygen. Are the two samples the same? Explain.

Cumulative Review

98. What is chemistry? *(Chapter 1)*

99. What is mass? Weight? *(Chapter 1)*

100. Express the following numbers in scientific notation. *(Chapter 2)*

a. 34,500 **d.** 789
b. 2665 **e.** 75,600
c. 0.9640 **f.** 0.002189

101. Perform the following operations. *(Chapter 2)*

a. $10^7 \times 10^3$
b. $(1.4 \times 10^{-3}) \times (5.1. \times 10^{-5})$
c. $(2 \times 10^{-3}) \times (4 \times 10^5)$

102. Convert 65°C to kelvins. *(Chapter 2)*

103. Graph the data in **Table 3.10.** What is the slope of the line? *(Chapter 2)*

Table 3.10 Energy Released by Carbon

Mass (g)	Energy Released (kJ)
1.00	33
2.00	66
3.00	99
4.00	132

Additional Assessment

WRITING in Chemistry

104. Synthetic Elements Select a synthetic element, and prepare a short written report on its development. Be sure to discuss recent discoveries, list major research centers that conduct this type of research, and describe the properties of the synthesized element.

DBQ Document-Based Questions

Pigments *Long before scientists understood the properties of elements and compounds, artists used chemistry to create pigments from natural materials.* **Table 3.11** *gives some examples of such pigments used in ancient times.*

Data obtained from: Orna, Mary Virginia. 2001. Chemistry, color, and art. *Journal of Chemical Education* 78 (10): 1305

Table 3.11 Common Artists' Pigments Used in Early Times

Common Name	Chemical Identity	Comments
Charcoal	elemental carbon (carbon black)	produced by dry distillation of wood in a closed vessel
Egyptian blue	calcium copper tetrasilicate, $CaCuSi_4O_{10}$	crystalline compound containing some glass impurity
Indigo	indigotin, $C_{16}H_{10}N_2O_2$	derived from different plants of the genus *Indigofera*
Iron oxide red	Fe_2O_3	in continuous use in all geographic regions and time periods
Verdigris	dibasic acetate of copper, $Cu(C_2H_3O_2)_2{\cdot}2Cu(OH)_2$	other copper compounds, including carbonate, are also called verdigris

105. a. Compare the mass percent of carbon in charcoal, indigo, and verdigris.

b. Compare the mass percent of oxygen in iron oxide and Egyptian blue.

106. List an example of an element and a compound from **Table 3.11.**

107. Is the production of charcoal from the dry distillation of wood a chemical or a physical change? Explain.

Cumulative

Standardized Test Practice

Multiple Choice

Use the table below to answer Questions 1 and 2.

Mass Analysis of Two Chlorine-Fluorine Samples				
Sample	Mass of Chlorine (g)	Mass of Fluorine (g)	% Cl	% F
I	13.022	6.978	65.11	34.89
II	5.753	9.248	?	?

1. What are the values for % Cl and % F, respectively, for Sample II?
A. 0.622 and 61.65
B. 61.65 and 38.35
C. 38.35 and 0.622
D. 38.35 and 61.65

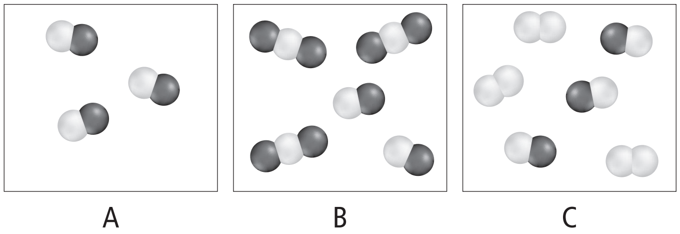
2. Which statement best describes the relationship between the two samples?
A. The compound in Sample I is the same as in Sample II. Therefore, the mass ratio of Cl to F in both samples will obey the law of definite proportions.
B. The compound in Sample I is the same as in Sample II. Therefore, the mass ratio of Cl to F in both samples will obey the law of multiple proportions.
C. The compound in Sample I is not the same as in Sample II. Therefore, the mass ratio of Cl to F in both samples will obey the law of definite proportions.
D. The compound in Sample I is not the same as in Sample II. Therefore, the mass ratio of Cl to F in both samples will obey the law of multiple proportions.

3. After two elements react to completion in a closed container, the ratio of their masses in the container will be the same as before the reaction. Which law describes this principle?
A. law of definite proportions
B. law of multiple proportions
C. law of conservation of mass
D. law of conservation of energy

4. Which is NOT a physical property of table sugar?
A. forms solid crystals at room temperature
B. appears as white crystals
C. breaks down into carbon and water vapor when heated
D. tastes sweet

5. Which describes a substance that is in the solid state?
A. Its particles can flow past one another.
B. It can be compressed into a smaller volume.
C. It takes the shape of its container.
D. Its particles of matter are close together.

Use the diagram below to answer Questions 6 and 7.



6. Which best describes Figure A?
A. element
B. mixture
C. solution
D. compound

7. Which statement is false?
A. Figure B is composed of two different compounds.
B. Figure C is composed of two different compounds.
C. Figure B represents 13 total atoms.
D. Three different types of elements are represented in Figure C.

8. Na, K, Li, and Cs all share similar chemical properties. In the periodic table of elements, they most likely belong to the same
A. row.
B. period.
C. group.
D. element.

9. Magnesium reacts explosively with oxygen to form magnesium oxide. Which is NOT true of this reaction?
A. The mass of magnesium oxide produced equals the mass of magnesium consumed plus the mass of oxygen consumed.
B. The reaction describes the formation of a new substance.
C. The product of the reaction, magnesium oxide, is a chemical compound.
D. Magnesium oxide has physical and chemical properties similar to both oxygen and magnesium.

Short Answer

10. Compare and contrast the independent variable in an experiment with the dependent variable.

11. A student reports the melting point of a gas as −295°C. Explain why his claim is unlikely to be correct.

12. Place the following metric prefixes in order from the smallest value to the largest value: deci, kilo, centi, micro, mega, milli, giga, nano.

Extended Response

Use the table below to answer Questions 13 to 15.

Selected Properties of Substances in a Mixture				
Item	Soluble in Water?	Soluble in Alcohol?	Density (g/cm^3)	Particle Size (mm)
Sawdust	no	no	0.21	1
Mothball flakes	no	yes	1.15	3
Table salt	yes	no	2.17	2

13. Is the mixture described in the table homogeneous or heterogeneous? Explain how you can tell.

14. Do the data describe chemical or physical properties? Explain your answer.

15. Propose a method to separate the three substances based on the properties described above.

16. Explain the difference between a chemical change and a physical change. Is the combustion of gasoline a chemical change or a physical change? Explain your answer.

SAT Subject Test: Chemistry

17. Which is a correct statement about methods for separating mixtures?
    A. Distillation results in the formation of solid particles of a dissolved substance.
    B. Filtration depends on differences in sizes of particles.
    C. Separations depend on the chemical properties of the substances involved.
    D. Chromatography depends on the different boiling points of substances.
    E. Sublimation can be used to separate two gases present in a mixture.

Use the table below to answer Questions 18 and 19.

Percent by Mass of Carbon, Hydrogen, and Oxygen in Selected Compounds			
Compound	% H	% C	% O
Carbonic acid (H_2CO_3)	3.2	19.4	77.4
Acetic acid (CH_3COOH)	6.7	40.0	53.3
Methanol (CH_3OH)	12.5	37.5	40.0
Methanal (H_2CO)	6.7	40.0	53.3
Isopropanol (C_3H_8O)	13.3	60.0	26.7

18. You have a 125-g sample of one of these substances. You determine that it is made of 16.7 g H, 75.0 g C, and 33.3 g O. Which compound is it?
    A. acetic acid
    B. carbonic acid
    C. methanal
    D. methanol
    E. isopropanol

19. In another experiment, you determine that a sample of acetic acid consists of 56.8% oxygen. What is your percent error?
    A. 3.50%
    B. 6.57%
    C. 1.07%
    D. 12.6%
    E. 2.06%

NEED EXTRA HELP?																			
If You Missed Question . . .	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Review Section . . .	3.4	3.4	3.2	3.1	3.1	3.4	3.3	3.4	3.2	1.3	2.1	2.1	3.3	3.1	3.3	3.1	3.3	3.4	2.3