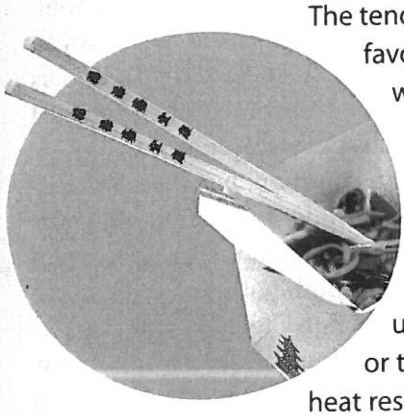
# 2.1 Properties of Matter

## Connecting to Your World

The more than 1200 species of bamboo belong to a family of grasses that includes wheat and corn. In tropical regions, bamboo plants grow rapidly to great heights. The tender shoots of some bamboo plants are a favorite food of pandas. People use the woody stems of mature plants to make furniture, fishing rods, and flooring. Because bamboo is inexpensive and abundant, disposable chopsticks are usually made from bamboo. Bamboo has properties that make it a good choice for use in chopsticks. It has no noticeable odor or taste. It is hard, yet easy to split, and it is heat resistant. In this section, you will learn how properties can be used to classify and identify matter.



### Guide for Reading

**Key Concepts**

- How can properties used to describe matter be classified?
- Why do all samples of a substance have the same intensive properties?
- What are three states of matter?
- How can physical changes be classified?

**Vocabulary**

mass
volume
extensive property
intensive property
substance
physical property
solid
liquid
gas
vapor
physical change

**Reading Strategy**

**Using Prior Knowledge** Before you read, write a definition for the term *liquid*. After you read this section, compare and contrast the definition of *liquid* in the text with your original definition.

## Describing Matter

Understanding matter begins with observation and what you observe when you look at a particular sample of matter is its properties. Is a solid shiny or dull? Does a liquid flow quickly or slowly? Is a gas odorless or does it have a smell? **Properties used to describe matter can be classified as extensive or intensive.**

**Extensive Properties** Recall that matter is anything that has mass and takes up space. The **mass** of an object is a measure of the amount of matter the object contains. The mass of a bowling ball with finger holes is five or six times greater than the mass of the bowling ball shown in Figure 2.1, which is used to play a game called candlepins. There is also a difference in the volume of the balls. The **volume** of an object is a measure of the space occupied by the object. Mass and volume are examples of extensive properties. An **extensive property** is a property that depends on the amount of matter in a sample.

**Intensive Properties** There are properties to consider when selecting a bowling ball other than mass. Beginning bowlers want a bowling ball that is likely to maintain a straight path. They use bowling balls with a hard surface made from polyester. Experienced bowlers want a bowling ball they can curve, or hook, toward the pins. Often, they use a polyurethane ball, which has a softer surface. Hardness is an example of an intensive property. An **intensive property** is a property that depends on the type of matter in a sample, not the amount of matter.

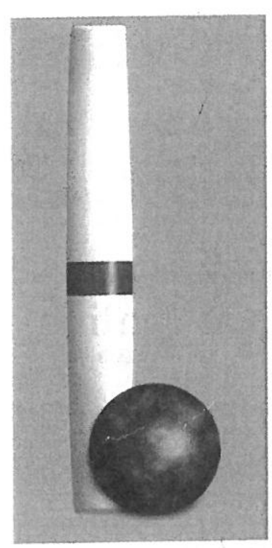
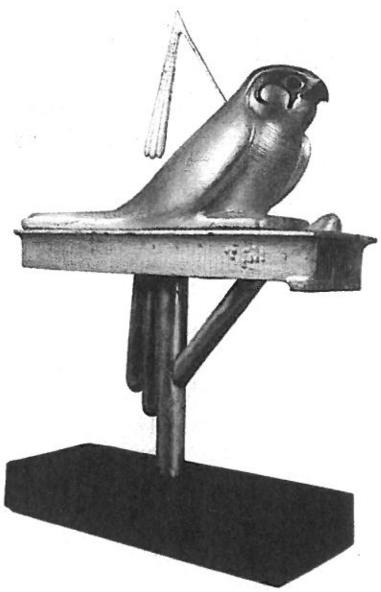


**Figure 2.1** This bowling ball and candlepin are used in a game played mainly in New England.



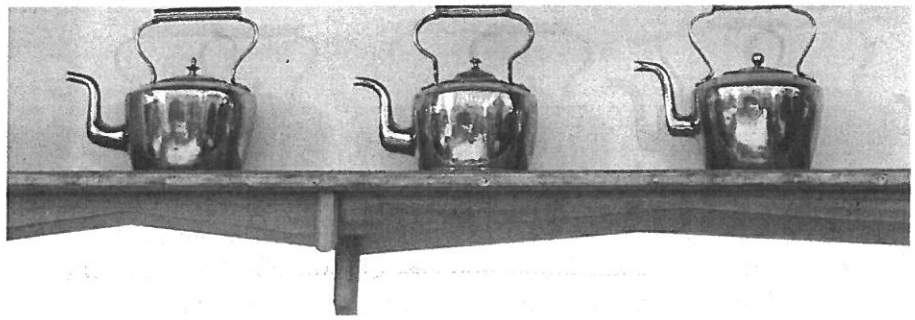


**Figure 2.2** This gold falcon standard from Egypt is about 3000 years old. The copper kettles are about 150 years old. **Analyzing Data** ***Which of the properties listed in Table 2.1 could not be used to distinguish copper from gold?***

## Identifying Substances

Each object in Figure 2.2 has a different chemical makeup, or composition. The sculpture of a falcon is mainly gold. The kettles are mainly copper. Matter that has a uniform and definite composition is called a **substance.** Gold and copper are examples of substances, which are also referred to as pure substances. **Every sample of a given substance has identical intensive properties because every sample has the same composition.**

Gold and copper have some properties in common, but there are differences besides their distinctive colors. Pure copper can scratch the surface of pure gold because copper is harder than gold. Copper is better than gold as a conductor of heat or electric current. Both gold and copper are malleable, which means they can be hammered into sheets without breaking. But gold is more malleable than copper. Hardness, color, conductivity, and malleability are examples of physical properties. A **physical property** is a quality or condition of a substance that can be observed or measured without changing the substance's composition.

Table 2.1 lists physical properties for some substances. The states of the substances are given at room temperature. (Although scientists use room temperature to refer to a range of temperatures, in this book it will be used to refer to a specific temperature, 20°C.) Physical properties can help chemists identify substances. For example, a colorless substance that was found to boil at 100°C and melt at 0°C would likely be water. A colorless substance that boiled at 78°C and melted at −117°C would most certainly not be water. Based on Table 2.1, it would likely be ethanol.

**Checkpoint** ***Which is a better conductor of electric current—gold or copper?***

**Table 2.1**

**Physical Properties of Some Substances**

| Substance | State | Color | Melting point (°C) | Boiling point (°C) |
|---|---|---|---|---|
| Neon | gas | colorless | −249 | −246 |
| Oxygen | gas | colorless | −218 | −183 |
| Chlorine | gas | greenish-yellow | −101 | −34 |
| Ethanol | liquid | colorless | −117 | 78 |
| Mercury | liquid | silvery-white | −39 | 357 |
| Bromine | liquid | reddish-brown | −7 | 59 |
| Water | liquid | colorless | 0 | 100 |
| Sulfur | solid | yellow | 115 | 445 |
| Sodium chloride | solid | white | 801 | 1413 |
| Gold | solid | yellow | 1064 | 2856 |
| Copper | solid | reddish-yellow | 1084 | 2562 |

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## States of Matter

Depending on the circumstances, you use three different words to refer to water—water, ice, and steam. Water, which is a common substance, exists in three different physical states. So can most other substances. **Three states of matter are solid, liquid, and gas.** Certain characteristics that can distinguish these three states of matter are summarized in Figure 2.3.

**Interactive Textbook**

**Animation 1** Relate the states of matter to the arrangements of their particles.

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**Solids** A **solid** is a form of matter that has a definite shape and volume. The shape of a solid doesn't depend on the shape of its container. The particles in a solid are packed tightly together, often in an orderly arrangement, as shown in Figure 2.3a. As a result, solids are almost incompressible; that is, it is difficult to squeeze a solid into a smaller volume. In addition, solids expand only slightly when heated.

**Liquids** Look at Figure 2.3b. The particles in a liquid are in close contact with one another, but the arrangement of particles in a liquid is not rigid or orderly. Because the particles in a liquid are free to flow from one location to another, a liquid takes the shape of the container in which it is placed. However, the volume of the liquid doesn't change as its shape changes. The volume of a liquid is fixed or constant. Thus, a **liquid** is a form of matter that has an indefinite shape, flows, yet has a fixed volume. Liquids are almost incompressible, but they tend to expand slightly when heated.

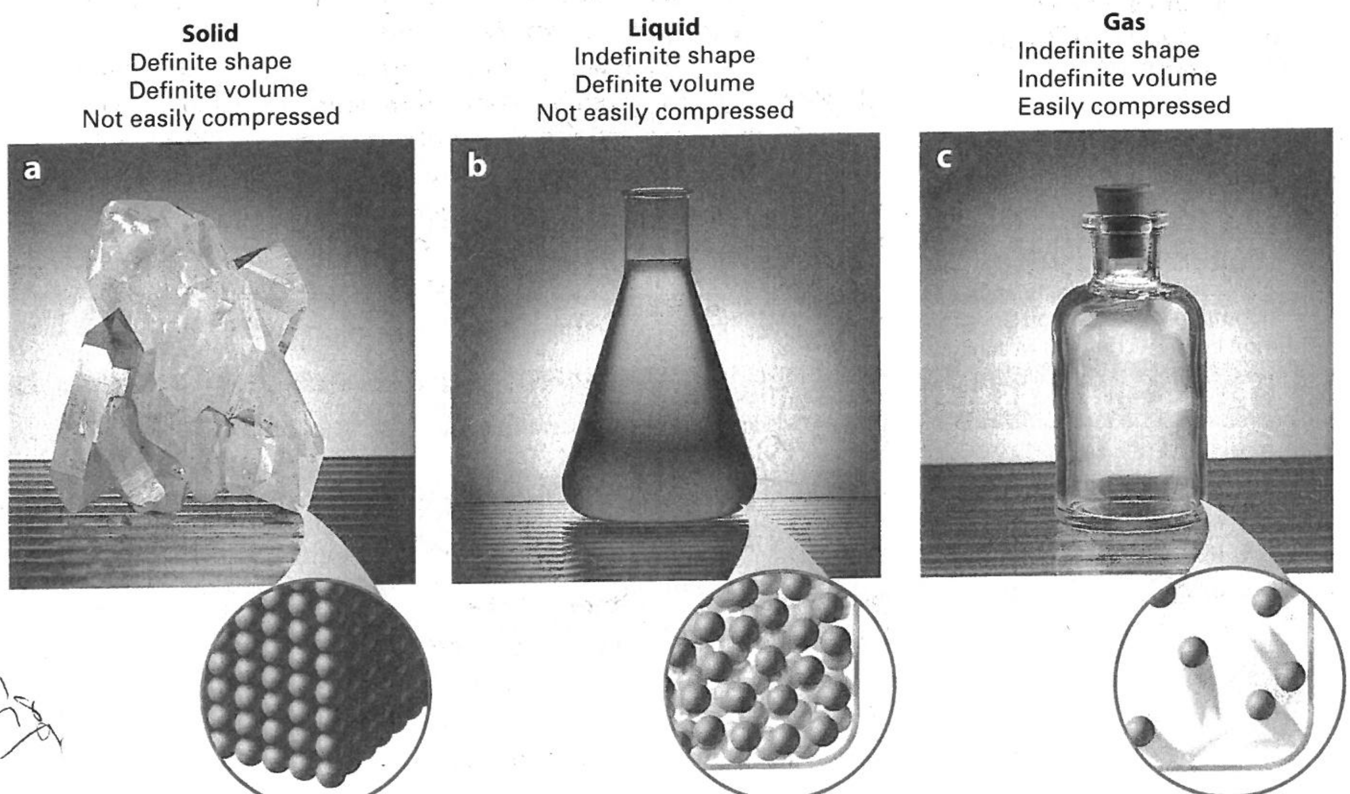


**Figure 2.3** The arrangement of particles is different in solids, liquids, and gases. (a) In a solid, the particles are packed closely together in a rigid arrangement. (b) In a liquid, the particles are close together, but they are free to flow past one another. (c) In a gas, the particles are relatively far apart and can move freely. **Relating Cause and Effect** ***Use the arrangements of their particles to explain the general shape and volume of solids and gases.***

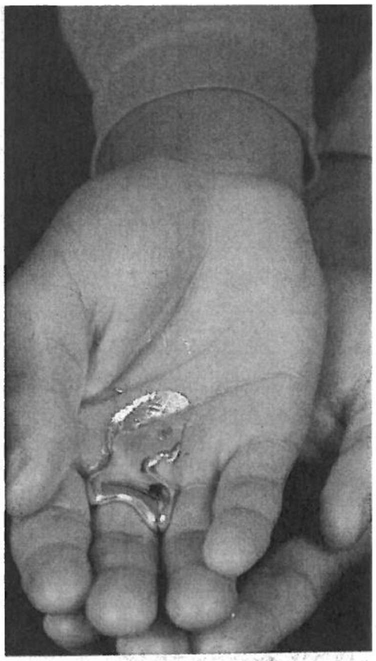

**Figure 2.4** The silvery substance in the photograph is gallium, which has a melting point of 30°C. **Inferring** ***What can you infer about the temperature of the hand holding the gallium?***

**Gases** Like a liquid, a gas takes the shape of its container. But unlike a liquid, a gas can expand to fill any volume. A **gas** is a form of matter that takes both the shape and volume of its container. Look back at Figure 2.3c. As shown in the model, the particles in a gas are usually much farther apart than the particles in a liquid. Because of the space between particles, gases are easily compressed into a smaller volume.

The words *vapor* and *gas* are sometimes used interchangeably. But there is a difference. The term *gas* is used for substances, like oxygen, that exist in the gaseous state at room temperature. (*Gaseous* is the adjective form of *gas*.) **Vapor** describes the gaseous state of a substance that is generally a liquid or solid at room temperature, as in water vapor.

**Checkpoint** ***When should the term vapor be used instead of gas?***

## Physical Changes

The melting point of gallium metal is 30°C. Figure 2.4 shows how heat from a person's hand can melt a sample of gallium. The shape of the sample changes during melting as the liquid begins to flow, but the composition of the sample does not change. Melting is an example of a physical change. During a **physical change,** some properties of a material change, but the composition of the material does not change.

Words such as *boil, freeze, melt,* and *condense* are used to describe physical changes. So are words such as *break, split, grind, cut,* and *crush.* However, there is a difference between these two sets of words. Each set describes a different type of physical change. **Physical changes can be classified as reversible or irreversible.** Melting is an example of a reversible physical change. If a sample of liquid gallium is cooled below its melting point, the liquid will become a solid. All physical changes that involve a change from one state to another are reversible. Cutting hair, filing nails, and cracking an egg are examples of irreversible physical changes.

## 2.1 Section Assessment

1. **Key Concept** Name two categories used to classify properties of matter.
2. **Key Concept** Explain why all samples of a given substance have the same intensive properties.
3. **Key Concept** Name three states of matter.
4. **Key Concept** Describe the two categories used to classify physical changes.
5. Which property in Table 2.1 can most easily distinguish sodium chloride from the other solids?
6. In what way are liquids and gases alike? In what way are liquids and solids different?
7. Is the freezing of mercury a reversible or irreversible physical change? Explain your answer.
8. Explain why samples of gold and copper can have the same extensive properties, but not the same intensive properties.

**Elements Handbook**

Read about the metal indium on page R16. What is the melting point of indium? Which other metal has a similar melting point—gallium or gold? Provide data to support your answer.

**Interactive Textbook**

**Assessment 2.1** Test yourself on the concepts in Section 2.1.

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# 2.2 Mixtures

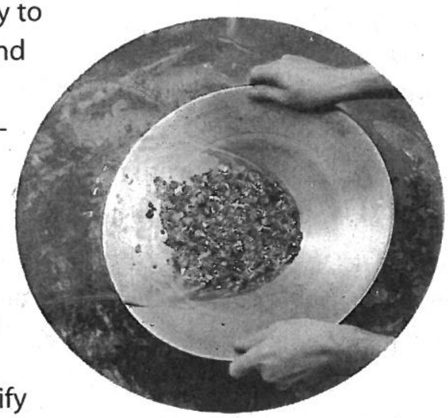
## Guide for Reading

**Key Concepts**
- How can mixtures be classified?
- How can mixtures be separated?

**Vocabulary**
mixture
heterogeneous mixture
homogeneous mixture
solution
phase
filtration
distillation

**Reading Strategy**
**Building Vocabulary** After you read this section, explain the difference between homogeneous and heterogeneous mixtures.

***Connecting to Your World*** In 1848, gold was discovered in California. This discovery led to a massive migration, or rush, of people to California. Panning is one way to separate gold from a mixture of gold and materials such as sand or gravel. A pan containing the mixture is placed underwater and shaken vigorously from left to right. This motion causes heavier materials, such as gold, to move to the bottom of the pan and lighter materials, such as sand, to move to the top where they can be swept away. In this section, you will learn how to classify and separate mixtures.



## Classifying Mixtures

A salad bar, like the one in Figure 2.5, provides a range of items, such as cucumbers and hot peppers. Customers choose which items to use in their salads and how much of each item to use. So each salad has a different composition. A **mixture** is a physical blend of two or more components.

Most samples of matter are mixtures. Some mixtures are easier to recognize than others. You can easily recognize chicken noodle soup as a mixture of chicken, noodles, and broth. Recognizing air as a mixture of gases is more difficult. But the fact that air can be drier or more humid shows that the amount of one component of air—water vapor—can vary. Chicken noodle soup and air represent two different types of mixtures. **Based on the distribution of their components, mixtures can be classified as heterogeneous mixtures or as homogeneous mixtures.**

**Figure 2.5** You can choose the amount of each item you select from a salad bar. So your salad is unlikely to have the same composition as other salads containing the same items.

## Quick LAB

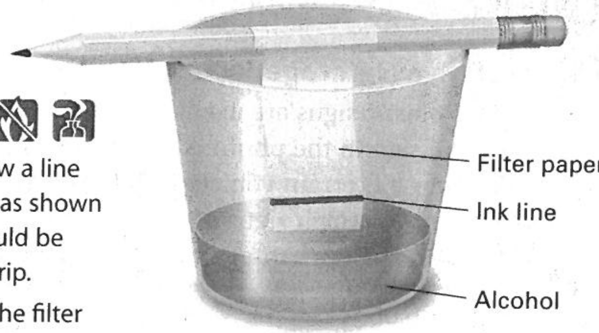
### Separating Mixtures

**Purpose**
To separate a mixture using paper chromatography.

**Materials**
- green marking pen
- filter paper strip
- metric ruler
- clear plastic tape
- pencil
- rubbing alcohol
- clear plastic drinking cup
- clear plastic wrap

**Procedure**

1. Use the marking pen to draw a line across a strip of filter paper, as shown in the drawing. The line should be 2 cm from one end of the strip.
2. Tape the unmarked end of the filter paper to the center of a pencil so that the strip hangs down when the pencil is held horizontally.
3. Working in a well-ventilated room, pour rubbing alcohol into a plastic cup to a depth of 1 cm.
4. Rest the pencil on the rim of the cup so that the ink end of the strip touches the rubbing alcohol, but does not extend below its surface. Use plastic wrap to cover the top of the cup.
5. Observe the setup for 15 minutes.




**Analyze and Conclude**

1. How did the appearance of the filter paper change during the procedure?
2. What evidence is there that green ink is a mixture?
3. How could you use this procedure to identify an unknown type of green ink?

**Heterogeneous Mixtures** In chicken noodle soup, the ingredients are not evenly distributed throughout the mixture. There is likely to be more chicken in one spoonful than in another spoonful. A mixture in which the composition is not uniform throughout is a **heterogeneous mixture.**

**Homogeneous Mixtures** The substances in the olive oil and vinegar in Figure 2.6 are evenly distributed throughout these mixtures. So olive oil doesn't look like a mixture. The same is true for vinegar. Vinegar is a mixture of water and acetic acid, which dissolves in the water. Olive oil and vinegar are homogeneous mixtures. A **homogeneous mixture** is a mixture in which the composition is uniform throughout. Another name for a homogeneous mixture is a **solution.** Many solutions are liquids. But some are gases, like air, and some are solids, like stainless steel, which is a mixture of iron, chromium, and nickel.

The term **phase** is used to describe any part of a sample with uniform composition and properties. By definition, a homogeneous mixture consists of a single phase. A heterogeneous mixture consists of two or more phases. When oil and vinegar are mixed, they form layers, or phases, as shown in Figure 2.6. The oil phase floats on the water phase.

**Checkpoint** ***How many phases are there in a homogeneous mixture?***

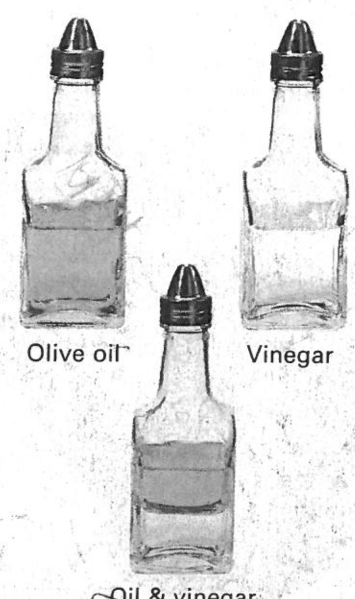
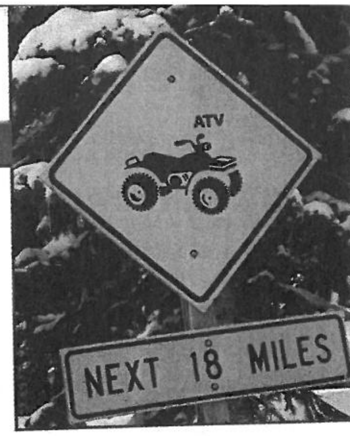



**Figure 2.6** Olive oil and vinegar are homogeneous mixtures. The substances in these mixtures are evenly distributed. When olive oil is mixed with vinegar, they form a heterogeneous mixture with two distinct phases.

## CONCEPTUAL PROBLEM 2.1

### Separating a Heterogeneous Mixture

Sometimes plastic signs are used to mark trails used by hikers or vehicles. The sign in the photo is used to mark locations along a trail where an all terrain vehicle (ATV) is permitted. Aluminum nails are used to attach signs at eye level to trees or posts. How could a mixture of aluminum nails and iron nails be separated?




**1 Analyze** ***Identify the relevant concepts.***

List properties of aluminum and iron.

Aluminum:
- metal
- gray color
- doesn't dissolve in water
- not attracted to magnet

Iron:
- metal
- gray color
- doesn't dissolve in water
- attracted to magnet

**2 Solve** ***Apply concepts to this situation.***

Identify a property that can be used to separate iron and aluminum objects. The ability to be attracted by a magnet is a property that iron and aluminum do not share. You could use a magnet to remove the iron nails from a mixture of iron and aluminum nails.

### Practice Problems

**9.** What physical properties could be used to separate iron filings from table salt?

**10.** Air is mainly a mixture of nitrogen and oxygen, with small amounts of other gases such as argon and carbon dioxide. What property could you use to separate the gases in air?

Interactive Textbook

**Problem Solving 2.10** Solve Problem 10 with the help of an interactive guided tutorial.

with ChemASAP

## Separating Mixtures

If you have a salad containing an ingredient you don't like, you can use a fork to remove the pieces of the unwanted ingredient. Many mixtures are not as easy to separate. To separate a mixture of olive oil and vinegar, for example, you could decant, or pour off, the oil layer. Or you might cool the mixture until the oil turned solid. The first method takes advantage of the fact that oil floats on water. The second method takes advantage of a difference in the temperatures at which the olive oil and vinegar freeze. **Differences in physical properties can be used to separate mixtures.**

**Filtration** The colander in Figure 2.7 can separate cooked pasta from the cooking water. The water passes through the holes in the colander, but the pasta does not. The holes, or pores, in a coffee filter are smaller than the holes in a colander to retain coffee grains. But the holes are not small enough to retain the particles in water. The process that separates a solid from the liquid in a heterogeneous mixture is called **filtration.**

**Figure 2.7** A colander is used to separate pasta from the water in which it was cooked. This process is a type of filtration.

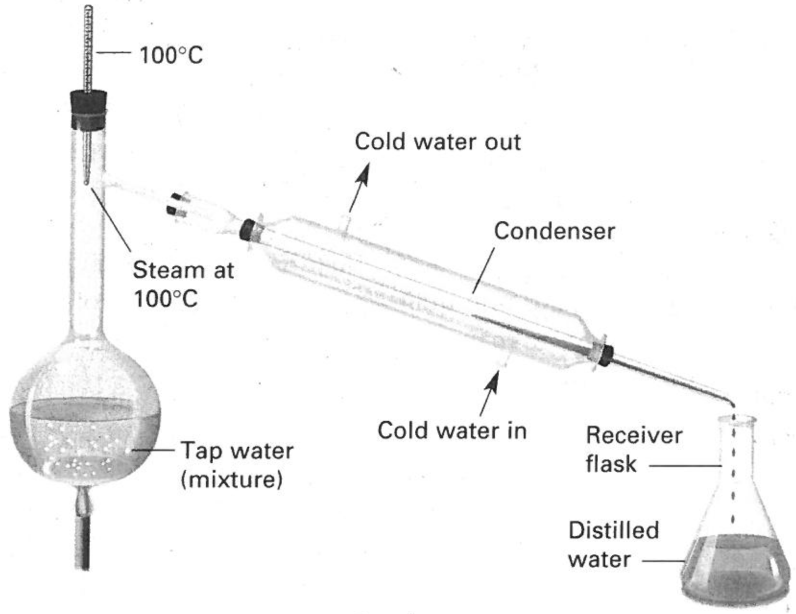



**Figure 2.8** A distillation can be used to remove impurities from water. As liquid water changes into water vapor, substances dissolved in the water are left behind in the distillation flask. **Inferring** ***What can you infer about the boiling points of substances dissolved in the impure water?***

**Distillation** Tap water is a homogeneous mixture of water and substances that dissolved in the water. One way to separate water from the other components in tap water is through a process called distillation. During a **distillation,** a liquid is boiled to produce a vapor that is then condensed into a liquid. Figure 2.8 shows an apparatus that can be used to perform a small-scale distillation.

As water in the distillation flask is heated, water vapor forms, rises in the flask, and passes into a glass tube in the condenser. The tube is surrounded by cold water, which cools the vapor to a temperature at which it turns back into a liquid. The liquid water is collected in a second flask. The solid substances that were dissolved in the water remain in the distillation flask because their boiling points are much higher than the boiling point of water.

## 2.2 Section Assessment

11. **Key Concept** How are mixtures classified?
12. **Key Concept** What type of properties can be used to separate mixtures?
13. Explain the term *phase* as it relates to homogeneous and heterogeneous mixtures.
14. Classify each of the following as a homogeneous or heterogeneous mixture.
    - **a.** food coloring
    - **b.** ice cubes in liquid water
    - **c.** mouthwash
    - **d.** mashed, unpeeled potatoes
15. How are a substance and a solution similar? How are they different?
16. In general, when would you use filtration to separate a mixture? When would you use distillation to separate a mixture?
17. Describe a procedure that could be used to separate a mixture of sand and table salt.

**Writing Activity**

**Writing to Persuade** Write a paragraph in support of this statement: Dry tea is a mixture, not a substance. Include at least two pieces of evidence to support your argument.

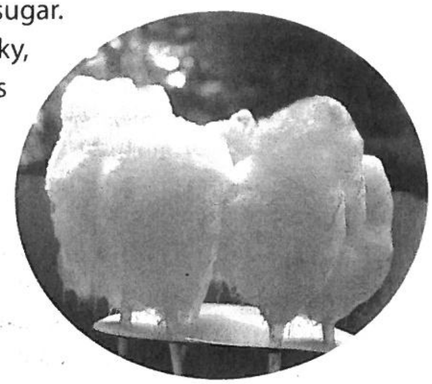
**Interactive Textbook**

**Assessment 2.2** Test yourself on the concepts in Section 2.2.

with **ChemASAP**

# 2.3 Elements and Compounds

**Connecting to Your World** Take two pounds of sugar, two cups of boiling water, and one-quarter teaspoon of cream of tartar. You have the ingredients to make spun sugar. Add food coloring and you have the sticky, sweet concoction sold at baseball games and amusement parks as cotton candy. Sugar is a substance that contains three other substances—carbon, hydrogen, and oxygen. In this section, you will learn how substances are classified as elements or compounds.



## Guide for Reading

### Key Concepts

- How are elements and compounds different?
- How can substances and mixtures be distinguished?
- What do chemists use to represent elements and compounds?

### Vocabulary

element
compound
chemical change
chemical symbol

### Reading Strategy

**Relating Text and Visuals** As you read, look at Figure 2.10. Explain how this illustration helps you understand the relationship between different kinds of matter.

## Distinguishing Elements and Compounds

Substances can be classified as elements or compounds. An **element** is the simplest form of matter that has a unique set of properties. Oxygen and hydrogen are two of the more than 100 known elements. A **compound** is a substance that contains two or more elements chemically combined in a fixed proportion. For example, carbon, oxygen, and hydrogen are chemically combined in the compound sucrose, the sugar in spun sugar. (Sometimes sucrose is referred to as table sugar to distinguish it from other sugar compounds.) In every sample of sucrose there are twice as many hydrogen particles as oxygen particles. The proportion of hydrogen particles to oxygen particles in sucrose is fixed. There is a key difference between elements and compounds. **Compounds can be broken down into simpler substances by chemical means, but elements cannot.**

**Breaking Down Compounds** Physical methods that are used to separate mixtures cannot be used to break a compound into simpler substances. Boil liquid water and you get water vapor, not the oxygen and hydrogen that water contains. Dissolve a sugar cube in water and you still have sucrose, not oxygen, carbon, and hydrogen. This result does not mean that sucrose or water cannot be broken down into simpler substances. But the methods must involve a chemical change. A **chemical change** is a change that produces matter with a different composition than the original matter. Heating is one of the processes used to break down compounds into simpler substances. The layer of sugar in Figure 2.9 is heated in a skillet until it breaks down into solid carbon and water vapor. Can the substances that are produced also be broken down?

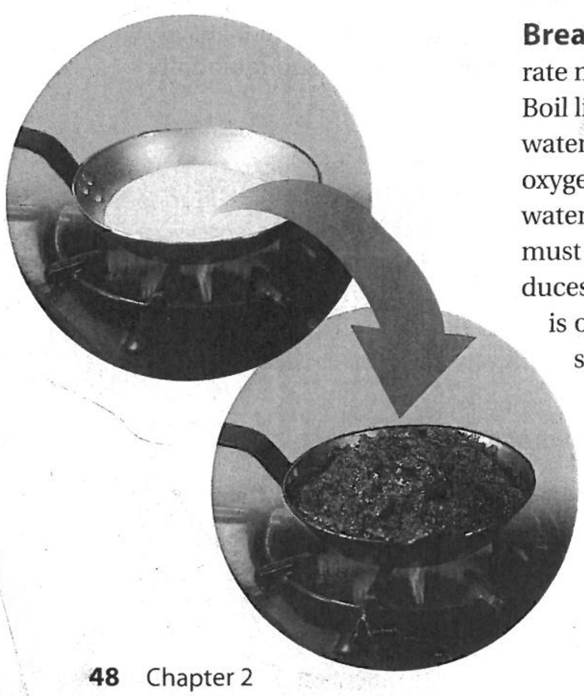


**Figure 2.9** When table sugar is heated, it goes through a series of chemical changes. The final products of these changes are solid carbon and water vapor.

There is no chemical process that will break down carbon into simpler substances because carbon is an element. Heating will not cause water to break down, but electricity will. When an electric current passes through water, oxygen gas and hydrogen gas are produced. The following diagram summarizes the overall process.

Chemical change

Sugar (Compound) $\xrightarrow{\text{heat}}$ Carbon (Element) + Water (Compound)

↓

Chemical change

Water (Compound) $\xrightarrow{\text{electricity}}$ Hydrogen (Element) + Oxygen (Element)

**Properties of Compounds** In general, the properties of compounds are quite different from those of their component elements. Sugar is a sweet-tasting, white solid, but carbon is a black, tasteless solid. Hydrogen is a gas that burns in the presence of oxygen—a colorless gas that supports burning. The product of this chemical change is water, a liquid that can stop materials from burning. Figure 2.10 shows samples of table salt (sodium chloride), sodium, and chlorine. When the elements sodium and chlorine combine chemically to form sodium chloride, there is a change in composition and a change in properties. Sodium is a soft, gray metal. Chlorine is a pale yellow-green poisonous gas. Sodium chloride is a white solid.

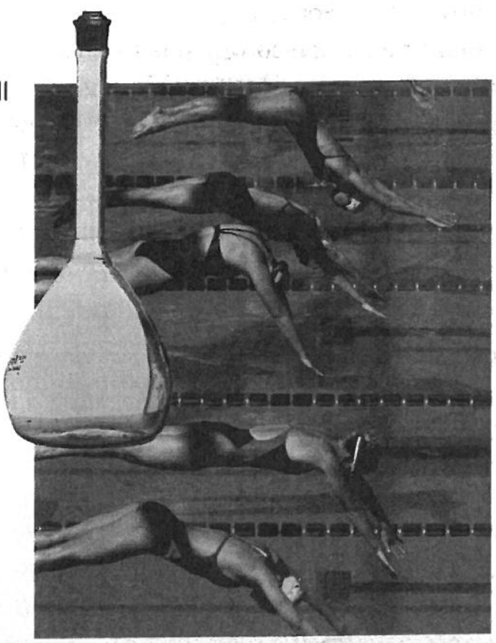
**Checkpoint** ***What process can be used to break down water?***

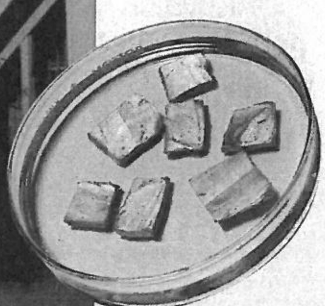
## Word *Origins*

**Compound** comes from a Latin word *componere,* meaning "to put together." Elements are put together, or chemically combined, in compounds. **What items are put together in a compound sentence?**

**Figure 2.10** Compounds and the elements from which they form have different properties. **Observing** ***Based on the photographs, describe two physical properties of sodium and two of chlorine.***

**Chlorine** is used to kill harmful organisms in swimming pools.





**Sodium** is stored under oil to keep it from reacting with oxygen or water vapor in air. Sodium vapor produces the light in some street lamps.

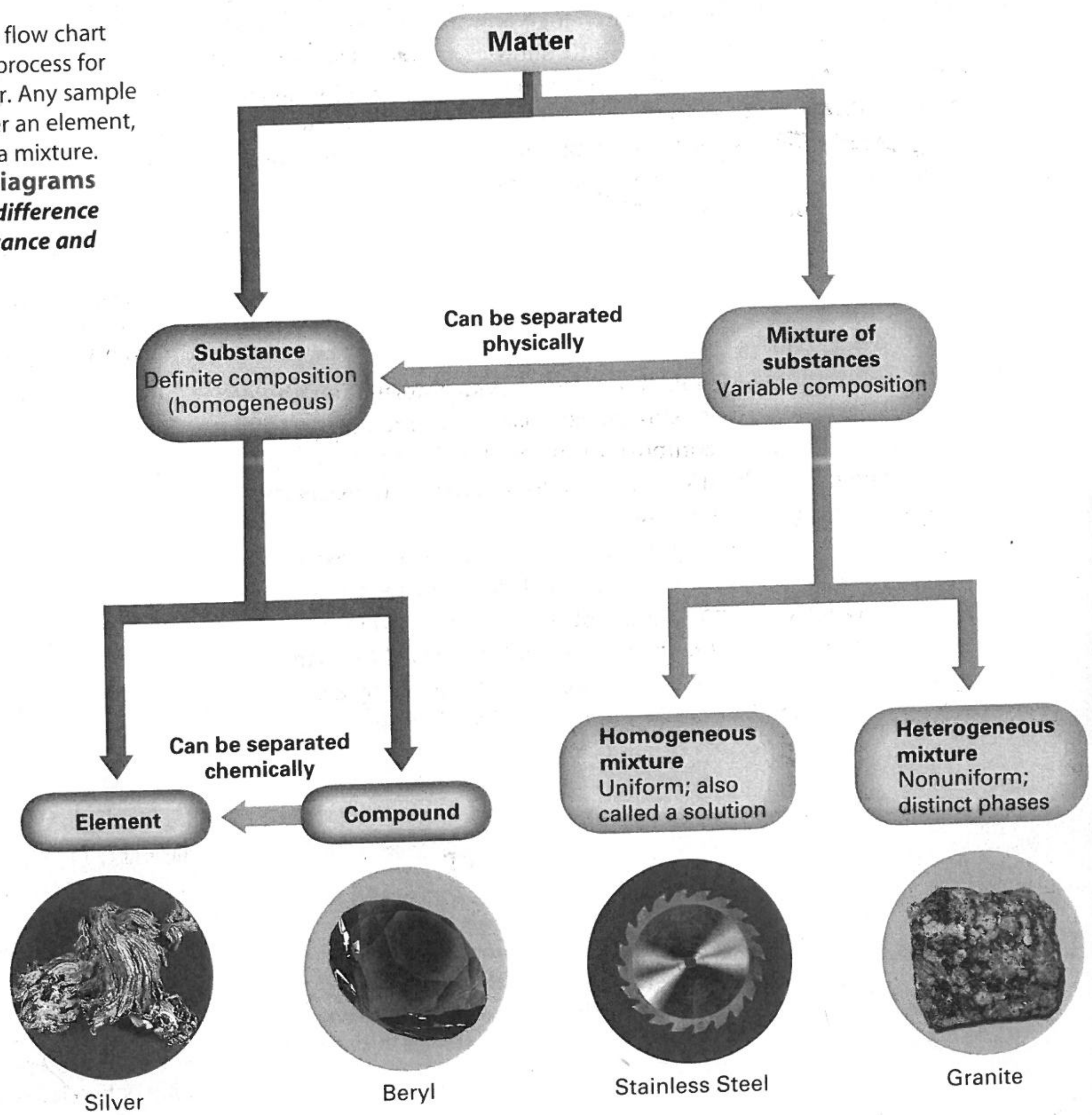
**Sodium chloride** (commonly known as table salt) is used to season or preserve food.

## Distinguishing Substances and Mixtures

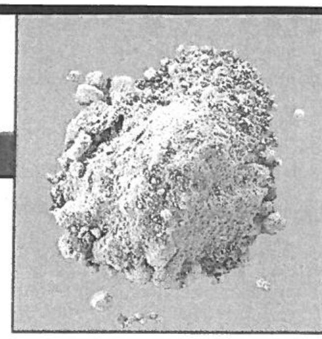
Deciding whether a sample of matter is a substance or a mixture based solely on appearance can be difficult. After all, homogeneous mixtures and substances will both appear to contain only one kind of matter. Sometimes you can decide by considering whether there is more than one version of the material in question. For example, you can buy whole milk, low-fat milk, no-fat milk, light cream, and heavy cream. From this information, you can conclude that milk and cream are mixtures. You might infer that these mixtures differ in the amount of fat they contain. Most gas stations offer at least two blends of gasoline. The blends have different octane ratings and different costs per gallon, with premium blends costing more than regular blends. So gasoline must be a mixture.

You can use their general characteristics to distinguish substances from mixtures. **If the composition of a material is fixed, the material is a substance. If the composition of a material may vary, the material is a mixture.** Figure 2.11 summarizes the general characteristics of elements, compounds, and mixtures.

**Figure 2.11** The flow chart summarizes the process for classifying matter. Any sample of matter is either an element, a compound, or a mixture.
**Interpreting Diagrams** ***What is the key difference between a substance and a solution?***



## CONCEPTUAL PROBLEM 2.2



### Classifying Materials

When the blue-green solid in the photograph is heated, a colorless gas and a black solid form. All three materials are substances. Is it possible to classify these substances as elements or compounds?

**1 Analyze** ***Identify the relevant concepts.***

List the known facts and relevant concepts.

- A blue-green solid is heated.
- A colorless gas and a black solid appear.
- A compound can be broken down into simpler substances by a chemical change, but an element cannot.
- Heating can cause a chemical change.

**2 Solve** ***Apply concepts to this situation.***

Determine if the substances are elements or compounds. Before heating, there was one substance. After heating there were two substances. The blue-green solid must be a compound. Based on the information given, it isn't possible to know if the colorless gas or black solid are elements or compounds.

### Practice Problems

**18.** Liquid A and Liquid B are clear liquids. They are placed in open containers and allowed to evaporate. When evaporation is complete, there is a white solid in container B, but no solid in container A. From these results, what can you infer about the two liquids?

**19.** A clear liquid in an open container is allowed to evaporate. After three days, a solid is left in the container. Was the clear liquid an element, a compound, or a mixture? How do you know?

Interactive Textbook

**Problem Solving 2.19** Solve Problem 19 with the help of an interactive guided tutorial.

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## Symbols and Formulas

The common names water and table salt do not provide information about the chemical composition of these substances. Also, words are not ideal for showing what happens to the composition of matter during a chemical change. **Chemists use chemical symbols to represent elements, and chemical formulas to represent compounds.**

Using symbols to represent different kinds of matter is not a new idea. Figure 2.12 shows some symbols that were used in earlier centuries. The symbols used today for elements are based on a system developed by a Swedish chemist, Jöns Jacob Berzelius (1779–1848). He based his symbols on the Latin names of elements. Each element is represented by a one- or two-letter **chemical symbol.** The first letter of a chemical symbol is always capitalized. When a second letter is used, it is lowercase.

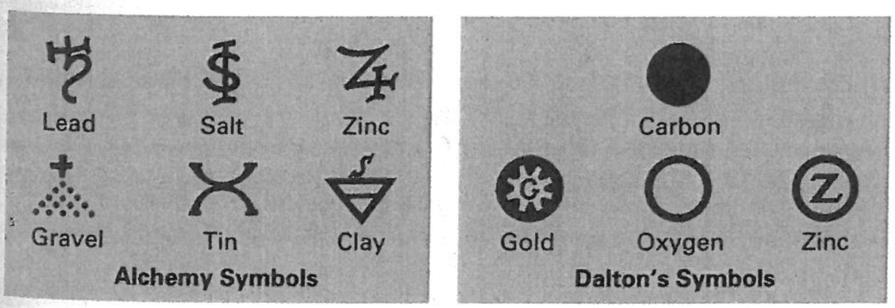


**Figure 2.12** The symbols used to represent elements have changed over time. Alchemists and the English chemist John Dalton (1766–1844) both used drawings to represent chemical elements. Today, elements are represented by one- or two-letter symbols.

## Table 2.2

**Symbols and Latin Names for Some Elements**

| Name | Symbol | Latin name |
|---|---|---|
| Sodium | Na | *natrium* |
| Potassium | K | *kalium* |
| Antimony | Sb | *stibium* |
| Copper | Cu | *cuprum* |
| Gold | Au | *aurum* |
| Silver | Ag | *argentum* |
| Iron | Fe | *ferrum* |
| Lead | Pb | *plumbum* |
| Tin | Sn | *stannum* |

**Go Online** SCILINKS (NSTA)

**For:** Links on Element Names
**Visit:** www.SciLinks.org
**Web Code:** cdn-1023

If the English name and the Latin name of an element are similar, the symbol will appear to have been derived from the English name. Examples include Ca for calcium, N for nitrogen, and S for sulfur. Table 2.2 shows examples of elements where the symbols do not match the English names.

Chemical symbols provide a shorthand way to write the chemical formulas of compounds. The symbols for hydrogen, oxygen, and carbon are H, O, and C. The formula for water is $H_2O$. The formula for sucrose, or table sugar, is $C_{12}H_{22}O_{11}$. Subscripts in chemical formulas are used to indicate the relative proportions of the elements in the compound. For example, the subscript 2 in $H_2O$ indicates that there are always two parts of hydrogen for each part of oxygen in water. Because a compound has a fixed composition, the formula for a compound is always the same.

## 2.3 Section Assessment

20. **Key Concept** How is a compound different from an element?
21. **Key Concept** How can you distinguish a substance from a mixture?
22. **Key Concept** What are chemical symbols and chemical formulas used for?
23. Name two methods that can be used to break down compounds into simpler substances.
24. Classify each of these samples of matter as an element, a compound, or a mixture.
    **a.** table sugar **b.** tap water
    **c.** cough syrup **d.** nitrogen
25. Write the chemical symbol for each element.
    **a.** lead **b.** oxygen
    **c.** silver **d.** sodium
    **e.** hydrogen **f.** aluminum
26. Name the chemical elements represented by the following symbols.
    **a.** C **b.** Ca **c.** K **d.** Au **e.** Fe **f.** Cu
27. What elements make up the pain reliever acetaminophen, chemical formula $C_8H_9O_2N$? Which element is present in the greatest proportion by number of particles?

**Writing Activity**

**Compare and Contrast Paragraph** Compare and contrast elements and compounds. Compare them by saying how they are alike. Contrast them by describing how they are different.

**Interactive Textbook**

**Assessment 2.3** Test yourself on the concepts in Section 2.3.

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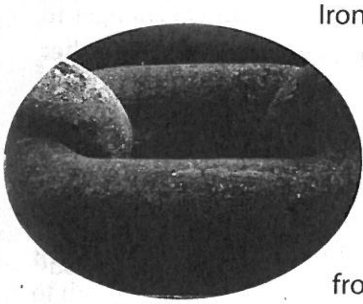
# 2.4 Chemical Reactions

## Connecting to Your World

Iron is an element with many desirable properties. It is abundant, easy to shape when heated, and relatively strong, especially when mixed with carbon in steel. Iron has one main disadvantage. Over time, objects made of iron will rust if they are left exposed to air. The brittle layer of rust that forms on the surface of the object flakes off, exposing more iron to the air. In this section, you will learn to recognize chemical changes and to distinguish them from physical changes.



### Guide for Reading

**Key Concepts**

- What always happens during a chemical change?
- What are four possible clues that a chemical change has taken place?
- How are the mass of the reactants and the mass of the products of a chemical reaction related?

**Vocabulary**

chemical property
chemical reaction
reactant
product
precipitate
law of conservation of mass

**Reading Strategy**

**Predicting** Before you read, predict what will happen to the mass of a sample of matter that burns. After you read, check the accuracy of your prediction and correct any misconceptions.

## Chemical Changes

The compound formed when iron rusts is iron oxide ($Fe_2O_3$). Words such as *burn, rot, rust, decompose, ferment, explode,* and *corrode* usually signify a chemical change. The ability of a substance to undergo a specific chemical change is called a **chemical property.** Iron is able to combine with oxygen to form rust. So the ability to rust is a chemical property of iron. Chemical properties can be used to identify a substance. But chemical properties can be observed only when a substance undergoes a chemical change.

Figure 2.13 compares a physical change and a chemical change that can occur in a mixture of iron and sulfur. When a magnet is used to separate iron from sulfur, the change is a physical change. The substances present before the change are the same substances present after the change, although they are no longer physically blended. Recall that during a physical change, the composition of matter never changes. **During a chemical change, the composition of matter always changes.** When the mixture of iron and sulfur is heated, a chemical change occurs. The sulfur and iron react and form iron sulfide (FeS).

A chemical change is also called a chemical reaction. One or more substances change into one or more new substances during a **chemical reaction.** A substance present at the start of the reaction is a **reactant.** A substance produced in the reaction is a **product.** In the reaction of iron and sulfur, iron and sulfur are reactants and iron sulfide is a product.

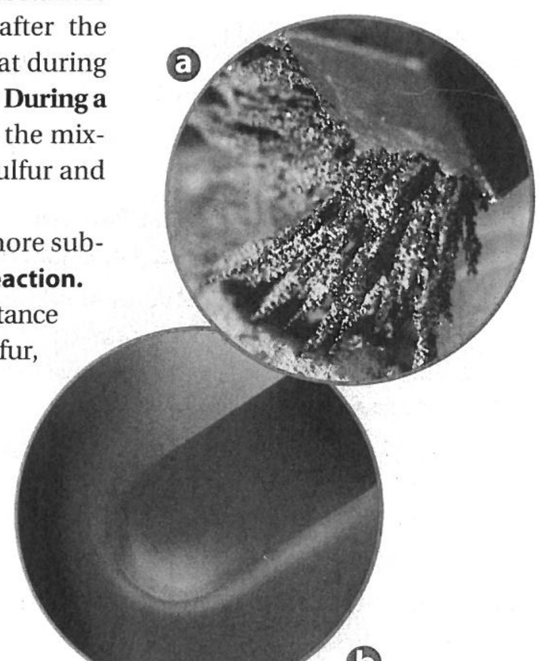



**Figure 2.13** A mixture of iron filings and sulfur can be changed. ⓐ A magnet separates the iron from the sulfur. ⓑ Heat combines iron and sulfur in a compound. **Classifying** ***Which change is a chemical change? Explain.***

## Recognizing Chemical Changes

How can you tell whether a chemical change has taken place? There are four clues that can serve as a guide. **Possible clues to chemical change include a transfer of energy, a change in color, the production of a gas, or the formation of a precipitate.**

Every chemical change involves a transfer of energy. For example, energy stored in natural gas is used to cook food. When the methane in natural gas combines with oxygen in the air, energy is given off in the form of heat and light. Some of this energy is transferred to and absorbed by food that is cooking over a lit gas burner. The energy causes chemical changes to take place in the food. The food may brown as it cooks, which is another clue that chemical changes are occurring.

You can observe two other clues to chemical change while cleaning a bathtub. The ring of soap scum that can form in a bathtub is an example of a precipitate. A **precipitate** is a solid that forms and settles out of a liquid mixture. Some bathroom cleaners that you can use to remove soap scum start to bubble when you spray them on the scum. The bubbles are a product of a chemical change that is taking place in the cleaner.

If you observe a clue to chemical change, you cannot be certain that a chemical change has taken place. The clue may be the result of a physical change. For example, energy is always transferred when matter changes from one state to another. Bubbles form when you boil water or open a carbonated drink. The only way to be sure that a chemical change has occurred is to test the composition of a sample before and after the change. Figure 2.14 shows examples of practical situations in which different clues to chemical change are visible.

**Checkpoint** ***What energy transfer takes place when food cooks?***

**Go Online** NSTA SCILINKS
**For:** Links on Chemical and Physical Changes
**Visit:** www.SciLinks.org
**Web Code:** cdn-1024

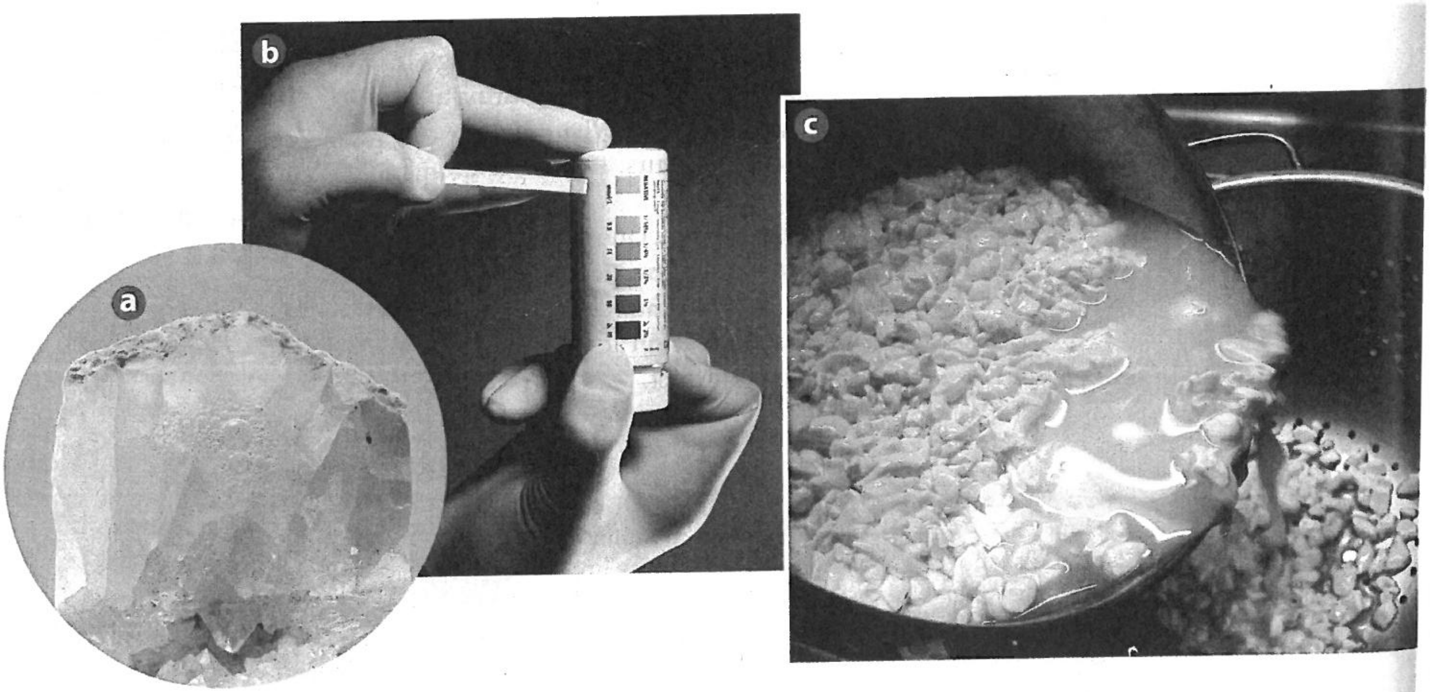


**Figure 2.14** Clues to chemical change often have practical applications. **a** Bubbles of carbon dioxide gas form when a geologist puts acid on a rock that contains compounds called carbonates. **b** When a test strip is dipped in urine, the color change is used to estimate the level of the sugar glucose in urine. **c** One step in the production of cheese is a reaction that causes milk to separate into solid curds and liquid whey.

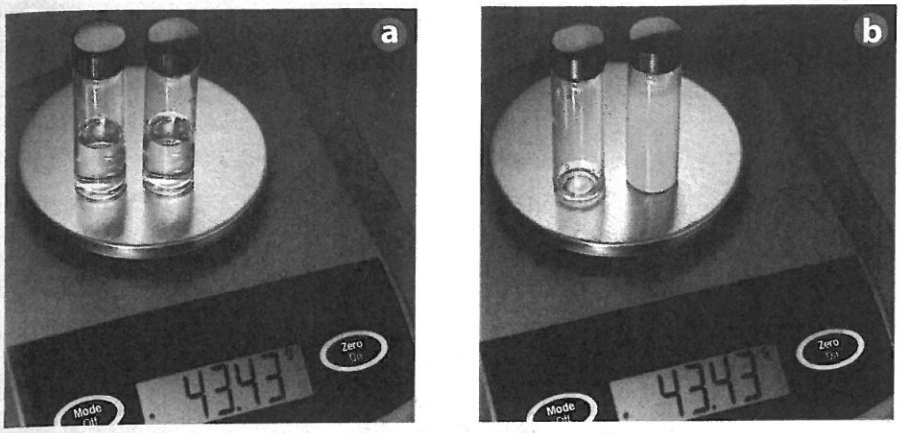



**Figure 2.15** When the liquids in photograph A are mixed, they react. None of the products are gases. **Analyzing Data** ***How do you know that a reaction took place and that mass was conserved during the reaction?***

## Conservation of Mass

When wood burns, substances in the wood combine with oxygen from the air. As the wood burns, a sizable amount of matter is reduced to a small pile of ashes. The reaction seems to involve a reduction in the amount of matter. But appearances can be deceiving. **During any chemical reaction, the mass of the products is always equal to the mass of the reactants.** Two of the products of burning wood—carbon dioxide gas and water vapor—are released into the air. When the mass of these gases is considered, the amount of matter is unchanged. Careful measurements show that the total mass of the reactants (wood and the oxygen consumed) equals the total mass of the products (carbon dioxide, water vapor, and ash).

Mass also holds constant during physical changes. For example, when 10 grams of ice melt, 10 grams of liquid water are produced. Similar observations have been recorded for all chemical and physical changes studied. The scientific law that reflects these observations is the law of conservation of mass. The **law of conservation of mass** states that in any physical change or chemical reaction, mass is conserved. Mass is neither created nor destroyed. The conservation of mass is more easily observed when a change occurs in a closed container, as in Figure 2.15.

## 2.4 Section Assessment

**28.** **Key Concept** How does a chemical change affect the composition of matter?

**29.** **Key Concept** Name four possible clues that a chemical change has taken place.

**30.** **Key Concept** In a chemical reaction, how does the mass of the reactants compare with the mass of the products?

**31.** What is the main difference between physical changes and chemical changes?

**32.** Classify the following changes as physical or chemical changes.

**a.** Water boils. **b.** Salt dissolves in water.
**c.** Milk turns sour. **d.** A metal rusts.

**33.** According to the law of conservation of mass, when is mass conserved?

**34.** Hydrogen and oxygen react chemically to form water. How much water would form if 4.8 grams of hydrogen reacted with 38.4 grams of oxygen?

### Connecting Concepts

**The Scientific Method** Lavoisier proposed the law of conservation of mass in 1789. Write a paragraph describing, in general, what Lavoisier must have done before he proposed this law. Use what you learned about the scientific method in Section 1.3.

**Interactive Textbook**

**Assessment 2.4** Test yourself on the concepts in Section 2.4.

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CHAPTER 2

# Assessment

## Reviewing Content

### 2.1 Properties of Matter

35. Describe the difference between an extensive property and an intensive property and give an example of each.
36. List three physical properties of copper.
37. Name two physical properties that could be used to distinguish between water and ethanol.
38. Name one physical property that could not be used to distinguish chlorine from oxygen.
39. What is the physical state of each of these materials at room temperature?
    a. gold
    b. gasoline
    c. neon
    d. olive oil
    e. oxygen
    f. mercury
40. Fingernail-polish remover (mostly acetone) is a liquid at room temperature. Would you describe acetone in the gaseous state as a vapor or a gas? Explain your answer.
41. Compare the arrangements of individual particles in solids, liquids, and gases.
42. Use Table 2.1 to identify four substances that undergo a physical change if the temperature is reduced from 50°C to −50°C. What is the physical change that takes place in each case?
43. Explain why sharpening a pencil is a different type of physical change than freezing water to make ice cubes.

### 2.2 Mixtures

44. What is the difference between homogeneous mixtures and heterogeneous mixtures?
45. How many phases does a solution have? Explain your answer.
46. Classify each of the following as homogeneous or heterogeneous mixtures.
    a. chocolate-chip ice cream
    b. green ink
    c. cake batter
    d. cooking oil
47. What is the goal of a distillation? Describe briefly how this goal is accomplished.

### 2.3 Elements and Compounds

48. How could you distinguish an element from a compound?
49. Describe the relationship between the three items in each of the following groups. Identify each item as an element, compound, or mixture.
    a. hydrogen, oxygen, and water
    b. nitrogen, oxygen, and air
    c. sodium, chlorine, and table salt
    d. carbon, water, and table sugar
50. Name the elements found in each of the following compounds.
    a. ammonia ($NH_3$)
    b. potassium oxide ($K_2O$)
    c. sucrose ($C_{12}H_{22}O_{11}$)
    d. calcium sulfide ($CaS$)
51. Not all element names come from English or Latin words. The symbol for tungsten is W from the German word *wolfram*. The symbol for mercury is Hg from the Greek word *hydragyrum*. Use the symbols W and Hg to explain the system of symbols for elements.
52. What does the formula $H_2O$ tell you about the composition of water?

### 2.4 Chemical Reactions

53. Use the word equation to explain how a chemical change differs from a physical change.

    $$\text{iron} + \text{sulfur} \xrightarrow{\text{heat}} \text{iron sulfide}$$
54. Classify each of the following as a physical or chemical change. For any chemical change, list at least one clue to support your answer.
    a. A copper wire is bent.
    b. Charcoal burns in a grill.
    c. Bread dough rises when yeast is added.
    d. Sugar dissolves in water.
55. Which type of property cannot be observed without changing the composition of a substance?
56. When ammonium nitrate ($NH_4NO_3$) explodes, the products are nitrogen, oxygen, and water. When 40 grams of ammonium nitrate explode, 14 grams of nitrogen and 8 grams of oxygen form. How many grams of water form?