section 2.2

MIXTURES

In 1848, gold was discovered in the foothills near Placerville, California. This discovery led to a massive gold rush in the following year. Many people in the California foothills still pan for gold as a hobby. Panning separates gold out of a mixture of gold and sand. **What is a mixture, and how can it be separated?**

objectives

- Categorize a sample of matter as a substance or a mixture
- Distinguish between homogeneous and heterogeneous samples of matter

key terms

- mixture
- heterogeneous mixture
- homogeneous mixture
- solutions
- phase
- distillation

Classifying Mixtures

You might prepare a salad by tossing lettuce, tomatoes, cucumbers, and celery with some vinegar and oil. The result is not only nutritious; it is also a mixture. In this section, you will learn how to identify and classify mixtures.

Most samples of matter are obviously mixtures. For example, you can easily recognize chicken noodle soup as a mixture of chicken pieces, noodles, and broth. Recognizing other materials as mixtures may be much harder. Air is a mixture of gases, but its components cannot be distinguished by eye, even through a microscope.

A **mixture** is a physical blend of two or more substances. One important characteristic of mixtures is that their compositions may vary. A dinner salad can have varying amounts of tomatoes or celery in it. The composition of air in a forest may differ from that in an industrial city, particularly in the amounts of pollutants. Blood, a mixture of water, various chemicals, and cells, varies somewhat in composition from one individual to another and, from time to time, in a given individual.

Mixtures can be of two basic kinds: heterogeneous or homogeneous. **Figure 2.3** gives examples of each kind. A **heterogeneous mixture** is one that is not uniform in composition. If you were to sample one portion of such a mixture, its composition would be different from that of another portion. Why is the salad described above heterogeneous? A **homogeneous mixture** in contrast, is one that has a completely uniform composition. Its components are evenly distributed throughout the sample. A sample of salt water is the same throughout. Thus salt water is an example of a homogeneous mixture.

Figure 2.3
All of these items are mixtures. The bar of soap and the beverage are homogeneous mixtures; they have uniform compositions. The salad is a heterogeneous mixture; it consists of several phases containing components that are not evenly distributed. What other everyday items can you identify as either homogeneous or heterogeneous mixtures?

Table 2.3

Some Common Types of Solutions	
System	**Examples**
Gas–gas	Carbon dioxide and oxygen in nitrogen (air)
Liquid–gas	Water vapor in air (moist air)
Gas–liquid	Carbon dioxide in water (soda water)
Liquid–liquid	Acetic acid in water (vinegar)
Solid–liquid	Sodium chloride in water (brine)
Solid–solid	Copper in silver (sterling silver, an alloy)

Homogeneous mixtures are so important in chemistry that chemists give them the special name of **solutions.** As **Table 2.3** shows, solutions may be gases, liquids, or solids. If you were to take a sample from any portion of a solution of sugar in water, you would find that it has the same composition as any other portion. Any part of a system with uniform composition and properties is called a **phase.** Thus a homogeneous mixture consists of a single phase. A heterogeneous mixture consists of two or more phases. A mixture of vinegar and oil is an example of a heterogeneous mixture with two phases. When the mixture is left unshaken, the separate phases are visible; the oil phase floats on the water phase.

Separating Mixtures

Some mixtures can be separated into their components by simple physical methods. You might use a fork to separate taco filling into meat, lettuce, cheese, and tomatoes. But separating the grayish mixture of powdered yellow sulfur and black iron filings, shown in **Figure 2.4**, is not so simple. The individual particles of sulfur and iron can be readily distinguished from one another under a microscope, so the mixture is heterogeneous. What property of iron makes using a magnet an effective way to separate the mixture?

Figure 2.4

The mixture of iron filings and sulfur can be separated using a magnet.

Tap water is a homogeneous mixture of water plus other substances that are dissolved in it. How would you separate the components in tap water? One method is called distillation. In **distillation,** a liquid is boiled to produce a vapor that is then condensed again to a liquid. **Figure 2.5** on page 34 shows an apparatus that can be used to perform a distillation. When water containing dissolved solids is distilled, it is first heated in a flask to form steam that enters a glass tube. The solid substances that originally dissolved in the water remain in the distillation flask because they do not change into a vapor. The steam cools and forms droplets of water inside the tube. The water drips into a receiver, where it is collected. The resulting distilled water is pure except for the dissolved gases it contains. Water from which even the dissolved gases are removed is a pure substance.

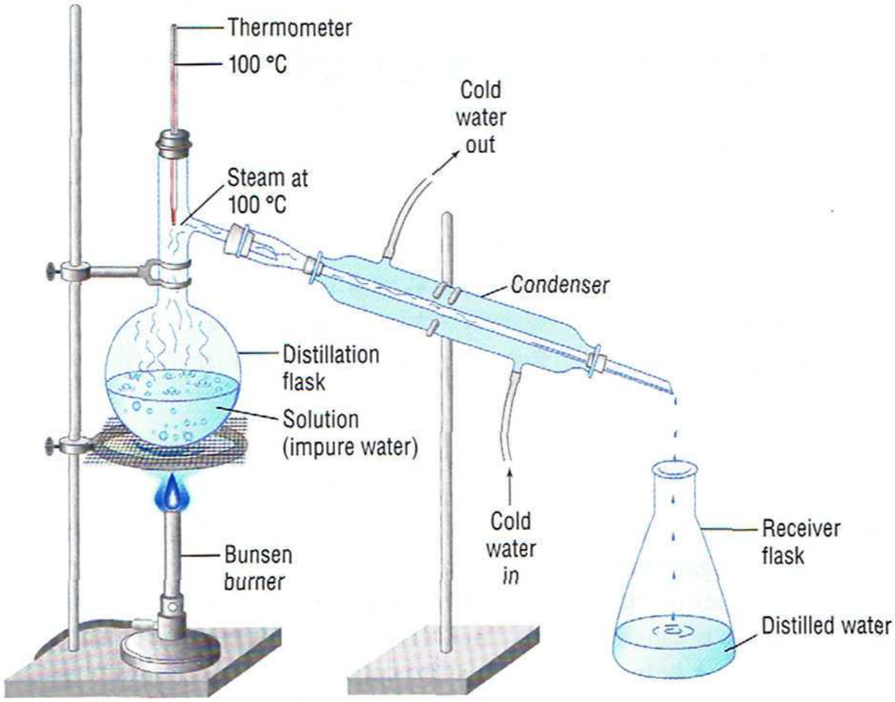


Figure 2.5

A solution of impure water is being distilled. As the solution boils, the water turns into steam, leaving the impurities behind in the distillation flask. As the steam passes through the water-cooled condenser, it turns to liquid. The distilled water is collected in the receiver flask.

Sample Problem 2-1

How can a mixture of iron filings and aluminum filings be separated?

1. **ANALYZE** *Plan a problem-solving strategy.*
List the properties of iron and aluminum and look for something that would be useful in separating the mixture.

2. **SOLVE** *Apply the problem-solving strategy.*

Iron:	*Aluminum:*
• metal	• metal
• grayish	• grayish
• not soluble in water	• not soluble in water
• attracted to a magnet	• not attracted to a magnet

Make use of a property that differentiates the metals; use a magnet to attract the iron filings.

3. **EVALUATE** *Does the result make sense?*
Because the magnet attracts iron but not aluminum filings, the iron would be removed while the aluminum would be left behind.

Practice Problems

5. What physical properties could be used to separate iron filings from salt?
6. Which of the following are homogeneous? Heterogeneous?
   a. spaghetti sauce
   b. glass
   c. muddy water
   d. cough syrup
   e. mixture of nitrogen gas and helium gas

Chem ASAP!

Problem-Solving 6

Solve Problem 6 with the help of an interactive guided tutorial.

MINI LAB

MIXTURES

PURPOSE

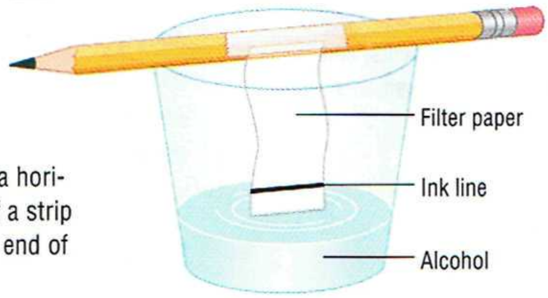
To separate a mixture using paper chromatography.

MATERIALS

- green marking pens
- strips of filter paper
- metric ruler
- clear plastic tape
- pencil
- rubbing alcohol
- clear plastic drinking cups
- clear plastic wrap
- water

PROCEDURE

1. Use the marking pen to draw a horizontal line across the width of a strip of filter paper, 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 end of the paper strip with the ink mark is just barely in contact with the rubbing alcohol. Carefully cover the top of the cup with plastic wrap.



5. Observe for 15 minutes.
6. If time permits, repeat this lab using different brands and different colors of pens. Also, try using water in place of rubbing alcohol.

ANALYSIS AND CONCLUSIONS

1. What appeared on the filter paper?
2. What did the results indicate about the nature of the green ink? Is the ink a mixture?

section review 2.2

7. What is the difference between a heterogeneous and a homogeneous mixture?
8. Describe a procedure that could be used to separate a mixture consisting of sand and salt.
9. Classify each of the following as a substance or a mixture.
   a. silver
   b. alphabet soup
   c. textbook
   d. table salt (sodium chloride)
10. Describe in your own words the difference between a pure substance and a mixture.
11. Describe ways in which the various components of a mixture can be separated.
12. Explain the term phase as it relates to homogeneous and heterogeneous mixtures.

Chem ASAP! Assessment 2.2 Check your understanding of the important ideas and concepts in Section 2.2.

section 2.3

ELEMENTS AND COMPOUNDS

objectives

- Explain the difference between an element and a compound
- Identify the chemical symbols of common elements, and name common elements, given their symbols

key terms

- elements
- compounds
- chemical symbol

Most people like sugar, a compound made of the elements carbon, hydrogen, and oxygen. Pure carbon is a black solid substance, pure hydrogen is a flammable gas, and pure oxygen is a gas that supports combustion. Yet these three elements combine in a particular way to form the white, sweet-tasting compound called sugar. **What is the difference between an element and a compound?**

Distinguishing Elements and Compounds

As you learned in the preceding section, a mixture can be physically separated into its components. Such a separation may yield pure substances, which have uniform and definite compositions. Substances themselves can be classified into two groups: elements and compounds. **Elements** are the simplest forms of matter that can exist under normal laboratory conditions. Elements cannot be separated into simpler substances by chemical means. They are the building blocks for all other substances. Oxygen, hydrogen, and carbon are examples of elements.

Two or more elements can combine chemically with one another to form compounds. For example, oxygen, hydrogen, and carbon can combine to produce the compound sucrose, or common table sugar. **Compounds** are substances that can be separated into simpler substances only by chemical means. There are a variety of chemical processes that can be used to separate compounds into simpler substances. Heating, as the photographs in **Figure 2.6** show, is one of these processes.

Heating a thin layer of sugar in a skillet demonstrates the difference between elements and compounds. With gentle heating, the sugar turns light brown. With continued heating, it turns black, breaking down completely into carbon and water vapor. This experiment shows that sugar is a compound, not an element. The chemical changes caused by strong heating break down the sugar into two different substances: carbon and water. But the question remains: Can the water and the carbon that are produced also be broken down, or are they elements? It turns out that water can be broken down into hydrogen and oxygen by another chemical change. Thus water, like sugar, is a compound. However, the carbon that is

(a) (b) (c)

Figure 2.6

To be separated into their component elements, compounds must undergo a chemical change. Here sugar is heated in a process known as caramelization. The intermediate and final products in photos ***(b)*** *and* ***(c)*** *look very different from the sugar in photo* ***(a)****. As water is completely removed, all that remains is charred, hardened carbon.*

produced by the heating process cannot be broken down into simpler substances. This shows that carbon is an element, not a compound. The following diagram illustrates the overall process just described.

$$\overbrace{\underset{\text{Compound}}{\text{Sugar}} \xrightarrow{\text{heat}} \underset{\text{Element}}{\text{Carbon}} + \underset{\text{Compound}}{\text{Water}}}^{\text{Chemical change}}$$

$$\downarrow$$

$$\overbrace{\underset{\text{Compound}}{\text{Water}} \xrightarrow{\text{electricity}} \underset{\text{Element}}{\text{Hydrogen}} + \underset{\text{Element}}{\text{Oxygen}}}^{\text{Chemical change}}$$

In general, the properties of compounds are quite different from those of their component elements. For example, the sugar placed in the skillet was a sweet, white solid, but the carbon that remained was a black, tasteless solid. Water is a colorless liquid, but oxygen and hydrogen are colorless gases. Table salt (sodium chloride) is a compound of the elements sodium and chlorine. Sodium is a soft metal that reacts explosively with water. Chlorine is a pale yellow-green poisonous gas. **Figure 2.7** shows how the physical appearances of sodium, chlorine, and sodium chloride differ.

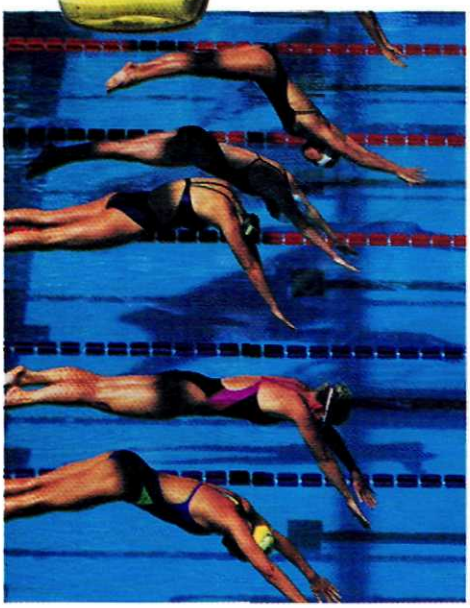


Figure 2.7
The compound sodium chloride is common table salt. It is composed of the elements sodium (below: a solid, stored under oil) and chlorine (far left: a gas). The photos show each substance in use: the highly reactive chlorine used to disinfect water, the sodium chloride used to season food, and the sodium used in a street lamp. Why must sodium metal ordinarily be stored under oil?

Deciding whether a sample of matter is a substance or a mixture can sometimes be difficult. After all, a homogeneous mixture looks like a substance. In some cases, you can decide by considering whether the material in question is always a single kind of material. For example, how would you classify gasoline? Based on its physical appearance, you might conclude that gasoline is a pure substance. However, it must be a mixture, because it exists in many different grades. Gasoline can have many different octane ratings and it may or may not contain alcohol. **Figure 2.8** summarizes some information about elements, compounds, and mixtures.

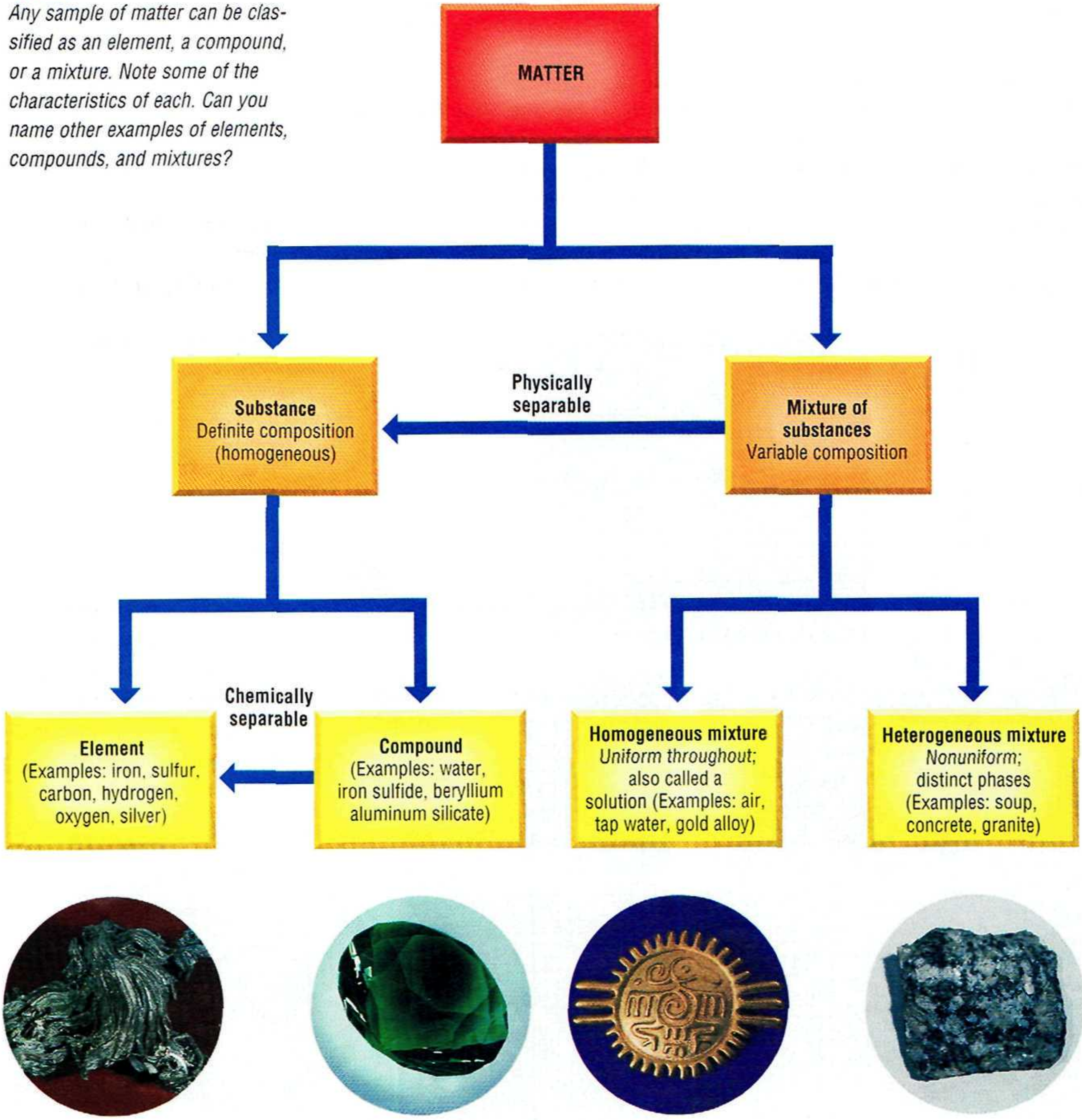


Figure 2.8
Any sample of matter can be classified as an element, a compound, or a mixture. Note some of the characteristics of each. Can you name other examples of elements, compounds, and mixtures?

Sample Problem 2-2

When a blue solid is heated in the absence of air, two other substances—a colorless gas and a white solid—are formed. Which of these substances are elements and which are compounds? Is it possible to tell? Explain.

1. **ANALYZE** ***Plan a problem-solving strategy.***
   List the known facts and determine if there is enough information to identify the substances by type (element or compound).
   - A blue solid is changed into two substances (a colorless gas and a white solid) when heated in the absence of air.
   - Compounds can be chemically broken down to simpler substances, but elements cannot be.
   - Heating can cause a chemical change.

2. **SOLVE** ***Apply the problem-solving strategy.***
   The blue solid was separated into two different substances by heating. Therefore, it must be a compound. The two resulting substances may be either elements or compounds—it is impossible to tell based on the information given.

3. **EVALUATE** ***Does the result make sense?***
   Given the limited amount of known information, the conclusions reached are reasonable.

Practice Problem

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

Chem ASAP!

Problem-Solving 13
Solve Problem 13 with the help of an interactive guided tutorial.

Symbols and Formulas

Carbon, hydrogen, oxygen, sodium, and chlorine are only a few of the more than 100 known elements. All matter in the universe is composed of these elements. Each element is represented by a one- or two-letter **chemical symbol.** The symbols for most elements consist of the first one or two letters of the element's name. **Table A.1** in the appendix gives the names and symbols for all of the elements. What is the symbol for the element ytterbium?

Note that the first letter of a chemical symbol is always capitalized. If a second letter is used, it is lowercase. Some chemical symbols are derived from Latin or Greek names for the element. In those cases, the symbol does not resemble the common name. **Table 2.4** lists such cases.

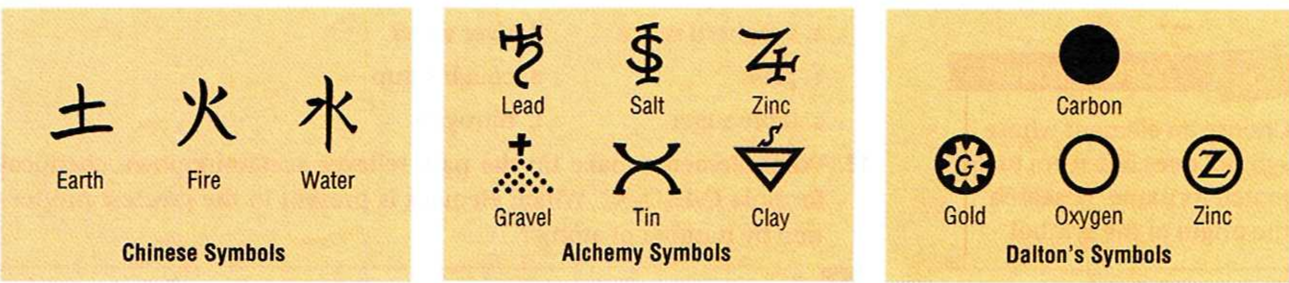


Figure 2.9
Many different symbols have been developed over time to represent chemicals, processes, and phenomena. This figure shows symbols used by the important eighteenth-century English chemist John Dalton, as well as some Chinese and alchemist symbols.

Link TO LINGUISTICS

Origins of Element Names

Many elements are named for the people who discovered them or the places where they were discovered. Some elements were given descriptive names taken from classical Latin or Greek. Others were named for figures in mythology. Polonium is named for Poland, the native land of Marie Curie, the discoverer of radium. Californium was discovered at the University of California. The word chlorine comes from the Greek *chloros*, meaning greenish-yellow; chlorine is a greenish-yellow gas. The name calcium is derived from the Latin *calx*, meaning lime. Calcium is a major component of limestone. You can find the origins of elements' names by consulting a dictionary or encyclopedia.

Table 2.4

Symbols and Name Origins for Some Elements

Name	Symbol	Latin or other 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*
Mercury	Hg	*hydrargyrum* (from Greek)
Tin	Sn	*stannum*
Tungsten	W	*wolfram* (from German)

Chemical symbols provide a shorthand way to write the chemical formulas of compounds. The compound water is composed of the elements hydrogen (H) and oxygen (O). The formula for water is H_2O. The formula for sucrose, or table sugar, is $C_{12}H_{22}O_{11}$. Sucrose is composed of the elements carbon (C), hydrogen (H), and oxygen (O). The subscript numbers in chemical formulas represent the proportions of the various elements in the compound. The elements that make up a compound are always present in the same proportions. Thus, in the case of water, there are always two parts of hydrogen for each part of oxygen. A specific compound is always made up of the same elements in the same proportions. Thus, the formula for a specific chemical compound is always the same.

section review 2.3

14. How can you distinguish between an element and a compound?

15. Write the chemical symbols for each of the following elements.

a. copper **b.** oxygen **c.** phosphorus **d.** silver **e.** sodium **f.** helium

16. Name the chemical elements represented by the following symbols.

a. Sn **b.** Ca **c.** S **d.** Cd **e.** P **f.** Cl

17. Classify each of these samples of matter as an element, a compound, or a mixture.

a. spaghetti sauce **b.** glass **c.** table sugar **d.** river water **e.** cough syrup **f.** nitrogen

18. 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 atoms?

Chem ASAP! Assessment 2.3 Check your understanding of the important ideas and concepts in Section 2.3.

portfolio project

Choose an element whose symbol does not seem to match its name. Research the origin of the symbol.

CHEMICAL REACTIONS

section 2.4

objectives

- Differentiate between physical and chemical changes in matter
- Apply the law of conservation of mass

key terms

- chemical reaction
- reactants
- products
- chemical property
- law of conservation of mass

Over a period of time, objects made out of iron will rust if they are left exposed to air. Rust is the product of a chemical reaction involving the reactants iron and oxygen. **What is a chemical reaction, and what are reactants and products?**

Changing Reactants to Products

Just as every substance has physical properties, each also has properties that relate to the kinds of chemical changes it can undergo. For example, iron has the property of being able to combine with oxygen to form rust. Such a change is an example of a chemical reaction. In a **chemical reaction,** one or more substances change into new substances. The original substances iron and oxygen combine to form a new substance, iron oxide, or rust. In chemical reactions, the starting substances are called **reactants,** and the substances formed are called **products.** What are the reactants in the reaction just described? What is the product?

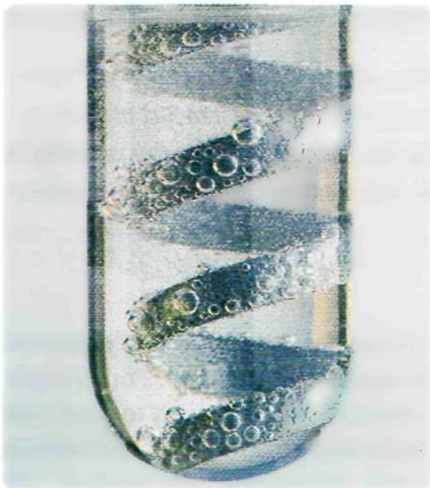
The ability of a substance to undergo a chemical reaction and to form new substances is called a **chemical property.** Rusting is a chemical property of iron. Chemical properties are observed only when a substance undergoes a chemical change. A chemical change always results in a change in chemical composition of the substances involved. Words such as burn, rot, rust, decompose, ferment, explode, and corrode usually signify a chemical change.

To help distinguish physical changes from chemical changes, recall the mixture of sulfur and iron filings discussed earlier. The separation of these substances by means of a magnet was an example of a physical change. If the same mixture is heated, however, a chemical reaction takes place. The sulfur and iron change into a new substance, iron sulfide. This change can be written in shorthand form as follows:

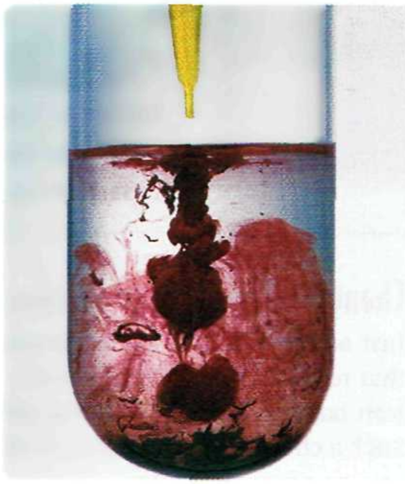
$$\text{iron} + \text{sulfur} \xrightarrow{\text{heat}} \text{iron sulfide}$$

Figure 2.10

The fizz of an antacid tablet dropped into a glass of water, the brilliance of fireworks exploding in the night sky, and the magnificent colors of autumn leaves are all examples of the chemical reactions you can see all around you.



(a)



(b)

Figure 2.11

The formation of a gas or a solid from a liquid or the production of a color change are common indications that a chemical change may be taking place. ***(a)*** *Zinc metal reacts with sulfuric acid solution to release hydrogen gas.* ***(b)*** *A red solid of silver chromate forms when a yellow solution of sodium chromate is added to a colorless solution of silver nitrate.*

LINK TO ENGINEERING

Chemical Engineers

Chemical engineers are employed by many industries, including companies that produce fuels, metals, plastics, chemicals, cosmetics, drugs, rubber, paper, paints, and foods. Chemical engineers must determine whether a reaction can be done in large enough amounts for mass production. They plan the layout of an industrial plant, design or select the equipment, and supervise the plant's construction and operation. They may add safety or pollution control features to comply with federal and state regulations. Chemical engineers are responsible for ensuring that the plant operates efficiently. They must also be aware of production costs and stay within a budget. Many engineering and technical schools offer degrees in chemical engineering. The course of study emphasizes chemistry, physics, mathematics, economics, writing, and computers. Specialized engineering courses are also required.

The arrow in the formula stands for the words "change into" or "produce." The reactants are written to the left of the arrow, the products to the right. How would you represent, in shorthand form, the reaction in which hydrogen and oxygen produce water? Several common chemical reactions are illustrated in **Figure 2.10** on page 41. You are probably familiar with many other chemical reactions.

How can you tell whether a chemical reaction has taken place? In general, there are several clues that may serve as a guide. The first is that energy is always absorbed or given off in chemical reactions. When you cook food, chemical changes that involve an absorption of heat take place. When you burn natural gas on a stove (another chemical reaction), heat is given off. However, energy is also absorbed or given off when the physical state of matter changes. Therefore, an energy change in itself is not proof of a chemical change. Other clues include a change in color or odor or the production of a gas or a solid from a liquid. See **Figure 2.11** for examples of chemical reactions that produce such changes. Once again, however, such clues are not always proof of a chemical change. For example, gas or vapor formation can be the result of a change of physical state and not a chemical change. When water boils, it changes from a liquid to a vapor, but the change is physical only; its chemical composition remains the same. A final indicator of chemical change is irreversibility. Physical changes, especially those involving a change of state, are usually reversible. Water can be melted and then refrozen. In contrast, most chemical changes are not easily reversed. For example, once iron has reacted with oxygen to form rust (iron oxide), as happens on a car, you cannot easily reverse the process and turn the rust back into iron.

Conservation of Mass

Combustion, or burning, is an example of one of the most familiar chemical changes. When you burn a lump of coal, atmospheric oxygen combines with the coal. The reaction produces carbon dioxide gas, water vapor, and a small ash residue. This change seems to involve a reduction in the amount of matter. A sizable piece of matter seems to have produced only a trace of ash. However, careful measurements show that the total mass of the reactants (the coal and the oxygen consumed) equals the total mass of the products (the carbon dioxide, water vapor, and ash) when the gases involved are taken into account.

During any chemical reaction, the quantity of matter is unchanged. The mass of products is always equal to the mass of reactants. Constancy of mass also holds for physical changes. For example, when 10 grams of ice melt, 10 grams of liquid water are obtained. Again, in this physical process, mass remains the same. Similar observations have been recorded for all chemical and physical changes studied. The **law of conservation of mass** is reflected in these observations and states that in any physical change or chemical reaction, mass is neither created nor destroyed; it is conserved. In every case, the mass of the products equals the mass of the reactants. One example of the conservation of mass is shown in **Figure 2.12.**

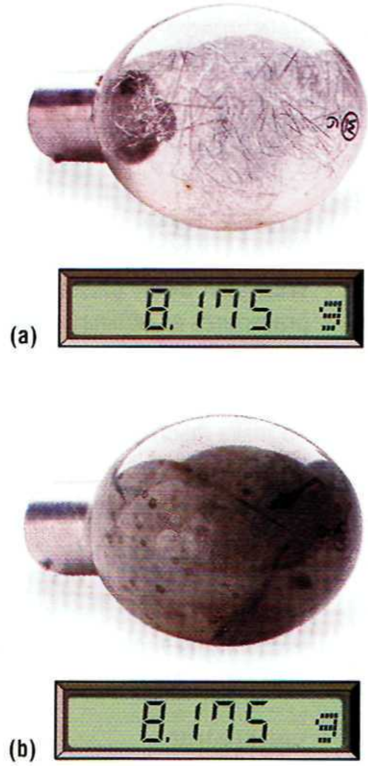


Figure 2.12
*Magnesium wire inside an old-fashioned flashbulb burns in oxygen gas to produce magnesium oxide. How do the mass readings for the unused bulb **(a)** and the used bulb **(b)** compare? What does this show about mass during the chemical reaction?*

section review 2.4

19. **a.** State the difference between a physical change and a chemical change, and list three likely indications that a chemical change has occurred. Which indication is most suggestive of a chemical reaction?

b. State the law of conservation of mass. How does the mass of reactants compare with the mass of products in a given reaction?

20. Classify the following changes as physical or chemical.

a. Cookies are baked.
b. Water boils.
c. Salt dissolves in water.
d. A firefly emits light.
e. Milk spoils.
f. A metal chair rusts.

21. Consider the law of conservation of mass as you answer this problem. When ammonium nitrate (NH_4NO_3) breaks down explosively, it forms nitrogen gas (N_2), oxygen gas (O_2), and water (H_2O). When 40 grams of ammonium nitrate explode, 14 grams of nitrogen and 8 grams of oxygen are formed. How many grams of water are formed?

22. State several physical or chemical properties that could be used to distinguish between each of the following pairs of substances and mixtures.

a. gasoline and water
b. copper and silver
c. water and a saltwater solution
d. aluminum and steel

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

Chem ASAP! Assessment 2.4 Check your understanding of the important ideas and concepts in Section 2.4.

SMALL-SCALE LAB

1 + 2 + 3 = BLACK!

SAFETY

Wear your safety glasses and follow standard safety procedures as outlined on page 18.

PURPOSE

To make macroscopic observations of chemical reactions and use them to solve problems.

MATERIALS

- pencil
- ruler
- chemicals shown in Figure A
- paper
- reaction surface
- pipette

PROCEDURE

Draw two grids similar to Figure A on separate sheets of paper. Make each square 2 cm on each side. Place a reaction surface over one of the grids and add one drop, *one piece, or a few grains of each chemical*, as shown in Figure A. Stir by blowing air through an empty pipette. Use the second grid as a data table to record your observations for each solution.

	$NaOCl$	H_2O_2	$CuSO_4$
KI			
KI + Starch			
KI + Paper			
KI + Cereal			

Figure A

ANALYSIS

Using your experimental data, record the answers to the following questions below your data table.

1. What color is a mixture of NaOCl and KI?
2. What happens when you mix NaOCl, KI, and starch?
3. NaOCl is a powerful bleaching agent as indicated by its reaction with KI and starch. Is hydrogen peroxide (H_2O_2) a bleaching agent? Explain.
4. What happens when you add NaOCl and KI to paper? What ingredient does this suggest the paper contains?
5. What ingredient is contained in cereal? How do you know?

YOU'RE THE CHEMIST!

The following small-scale activities allow you to develop your own procedures and analyze the results.

1. **Design It!** Design and carry out an experiment to see which foods contain starch.
2. **Design It!** Read the label on a package of iodized salt. How much KI does iodized salt contain? Design an experiment to prove the presence of KI in iodized salt and the absence of KI in regular salt.
3. **Design It!** Laundry detergents, automatic dish washing liquids, and cleansers sometimes contain a bleaching agent similar to NaOCl. The purpose of the bleach is to whiten clothes and remove stains. Design an experiment to decide which laundry detergents and cleansers contain bleach.
4. **Design It!** Antacid tablets and other pharmaceuticals often contain starch as a binder to hold the ingredients in the tablet together. Design and carry out an experiment to explore various antacid tablets to see if they contain starch.
5. **Analyze It!** Mix one drop of NaOCl on a piece of colored construction paper. What happens? Try inventing a technique that will create some original "bleach art."
6. **Analyze It!** Other bleaching agents include $FeCl_3$, KIO_3, $KMnO_4$, and $NaNO_2$. Try mixing these with KI and starch to see what happens. What is the best agent to detect the presence of KI in table salt?

BARRIERS TO HEAT FLOW

Will a hot drink stay hotter in a paper cup or in a foam cup? You probably know from experience that the foam cup will work better. In fact, the same foam cup will also do a good job of keeping a cold drink cold. The foam cup is effective at these jobs because polystyrene foam is a good *thermal insulator*.

A thermal insulator is a material that works as a barrier to the movement of thermal energy through matter. Thermal energy spreads from areas of higher temperature to areas of lower temperature, often very rapidly. This means that something hot, such as tea, will tend to lose its thermal energy to its surroundings. It also means that something cold, such as iced tea, will tend to be warmed by its surroundings. An insulator can slow the movement of thermal energy that causes the undesirable change in temperature.

Thermal insulators are everywhere in human society. They are used to keep houses warm and freezers cold. They keep you warm on a cold day and allow you to pick up a hot pan without getting burned. Because of the importance of insulators, chemists are always at work manipulating matter to make materials with good insulating properties.

Chemists are always at work manipulating matter to make materials with good insulating properties.

Many of the best insulators are materials in which air is trapped. Air is a good barrier to the movement of thermal energy as long as the air is not moving, and trapped pockets of air satisfy this requirement well.

Using insulation that has a network of thin fibers is an effective way to trap air. Consider fiberglass insulation, which is often used to insulate the walls and ceilings of houses. Fiberglass is just what its name implies—thin fibers of glass (silicon dioxide) that have been woven together. A wool sweater or fleece jacket insulates your body in the same way as fiberglass.

Foams are another type of insulating material. Foams differ from fiber networks in that their air pockets are completely enveloped by the solid material that makes up the framework of the foam.

Traditional polystyrene foam and other similar foams are excellent insulators, but researchers knew they could take these foams a step further. Their goal was to make foams with as little mass as possible for a given volume. The researchers succeeded in developing several new high-tech foams, which are very effective insulators.

One of these new foams, SEAgel, is made of agar, a carbohydrate material that comes from seaweed. SEAgel begins as a gelatin-like mixture of agar and water. Then it is freeze-dried to remove the water. What is left is a honeycomb of dried agar filled with air. The sample in the photograph is light enough to float on soap bubbles. In fact, SEAgel is among the least dense solids known with a density approximately equal to that of air! SEAgel is a very lightweight and efficient insulator. Because it is made entirely of biological material, it is completely biodegradable.

CHEMISTRY IN CAREERS

MATERIALS SCIENTIST
Want to design your own solid substances?
See page 868.

TAKE IT TO THE NET
Find out more about career opportunities:
www.phschool.com

CHEMIST NEEDED
Enviro. Lab. GC Must know EPA methods...

CHEMICAL SPECIALIST
Local food service distributor seeks responsibl...

Chapter 2 STUDENT STUDY GUIDE

Take It to the NET
For interactive study and review, go to www.phschool.com

KEY TERMS

- chemical property *p. 41*
- chemical reaction *p. 41*
- chemical symbol *p. 39*
- compound *p. 36*
- distillation *p. 33*
- element *p. 36*
- gas *p. 31*
- heterogeneous mixture *p. 32*
- homogeneous mixture *p. 32*
- law of conservation of mass *p. 43*
- liquid *p. 31*
- mass *p. 29*
- matter *p. 29*
- mixture *p. 32*
- phase *p. 33*
- physical change *p. 31*
- physical property *p. 29*
- product *p. 41*
- reactant *p. 41*
- solid *p. 30*
- solution *p. 33*
- substance *p. 29*
- vapor *p. 31*

KEY RELATIONSHIP

- Law of conservation of mass:

  mass of reactants = mass of products

CONCEPT SUMMARY

2.1 Matter

- Matter has mass and occupies space.
- The three common states of matter are solid, liquid, and gas.
- A pure substance contains one kind of matter.

2.2 Mixtures

- A mixture is a physical combination of two or more substances that can be separated by physical means.
- Heterogeneous mixtures are not uniform in composition.
- Homogeneous mixtures, also called solutions, have uniform properties throughout and may be gases, liquids, or solids.

2.3 Elements and Compounds

- Elements are the simplest forms of matter that exist under normal conditions.
- Elements are always present in the same ratio in a given compound.
- Properties of a compound are usually different from those of the elements composing it.
- Chemical methods are required to separate compounds into their constituent elements.
- Each element is represented by a one- or two-letter chemical symbol. Chemical symbols of the elements are used as a shorthand method of writing chemical formulas of compounds.

2.4 Chemical Reactions

- A physical change is a change in the physical properties of a substance without a change in chemical composition.
- A chemical change is a change in the chemical composition of a substance.
- In a chemical change (chemical reaction), reactants are converted to products. Mass is conserved in any physical or chemical change.

CHAPTER CONCEPT MAP

Use these terms to construct a concept map that organizes the major ideas of this chapter.

chemical reaction | matter | substance | element
law of conservation of mass | heterogeneous mixture | homogeneous mixture
physical property | compound | physical change | chemical property

Chem ASAP! Concept Map 2
Create your Concept Map using the computer.

CONCEPT PRACTICE

24. List three physical properties of an iron nail. *2.1*

25. What is the physical state of each of the following items at room temperature? *2.1*
- **a.** gold
- **b.** gasoline
- **c.** helium
- **d.** paraffin wax
- **e.** rubbing alcohol
- **f.** mercury

26. In which state of matter do the following exist at room temperature? *2.1*
- **a.** diamond
- **b.** oxygen
- **c.** cooking oil
- **d.** mercury
- **e.** clay
- **f.** neon

27. 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. *2.1*

28. List three substances that you have experienced in at least two physical states. *2.1*

29. Use **Table 2.1** to identify four substances that undergo a physical change if the temperature is decreased from 50 °C to −50 °C. Describe the nature of the physical change. *2.1*

30. Classify each of the following as homogeneous or heterogeneous mixtures. *2.2*
- **a.** blood
- **b.** chocolate-chip ice cream
- **c.** brass (a blend of copper and zinc)
- **d.** motor oil
- **e.** black coffee

31. How many phases does every solution have? Explain. *2.2*

32. Classify each of the following as an element or a mixture. *2.3*
- **a.** silver
- **b.** pine tree
- **c.** orange juice
- **d.** oxygen
- **e.** iced tea
- **f.** air

33. Name the elements found in each of the following compounds. *2.3*
- **a.** ammonium chloride (NH_4Cl)
- **b.** potassium permanganate ($KMnO_4$)
- **c.** isopropyl alcohol (C_3H_7OH)
- **d.** calcium iodide (CaI_2)

34. List four indications that a chemical change has probably taken place. *2.4*

35. Classify each of the following as a physical or chemical change. *2.4*
- **a.** bending a piece of wire
- **b.** burning coal
- **c.** cooking a steak
- **d.** cutting grass

36. When powdered iron is left exposed to the air, it rusts. Explain why the rust weighs more than the original powdered iron. *2.4*

37. A friend observes a burning candle and comments that the wax is lost as the candle burns. Having recently studied the law of conservation of mass, how would you correct your friend? *2.4*

CONCEPT MASTERY

38. Devise a way to separate sand from a mixture of charcoal, sand, sugar, and water.

39. Imagine first standing in the kitchen of your home and then in the middle of a park. When you view the surroundings in each location do you see mostly elements, compounds, or mixtures?

40. Use **Table 2.1** to answer each question.
- **a.** Which property most easily distinguishes sulfur from the other solid substances?
- **b.** How many of these substances are elements?
- **c.** Which compound has the highest boiling point?
- **d.** The solids are gradually heated. Which one will melt first?

41. Identify each of the following as a mixture or a compound. For the mixtures, classify each as homogeneous or heterogeneous.
- **a.** soda
- **b.** candle wax
- **c.** fog
- **d.** ink
- **e.** egg
- **f.** ice
- **g.** gasoline
- **h.** blood

42. Classify the following properties of the element silicon as chemical or physical properties.
- **a.** blue-gray color
- **b.** brittle
- **c.** insoluble in water
- **d.** melts at 1410 °C
- **e.** reacts vigorously with fluorine

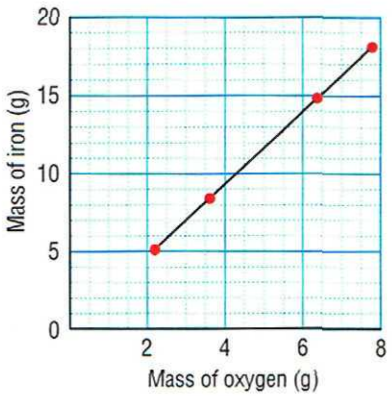
43. How do you know that each of these is a chemical change?
   a. Food spoils.
   b. A foaming antacid tablet fizzes in water.
   c. A ring of scum forms around your bathtub.
   d. Iron rusts.
   e. A firecracker explodes.

CRITICAL THINKING

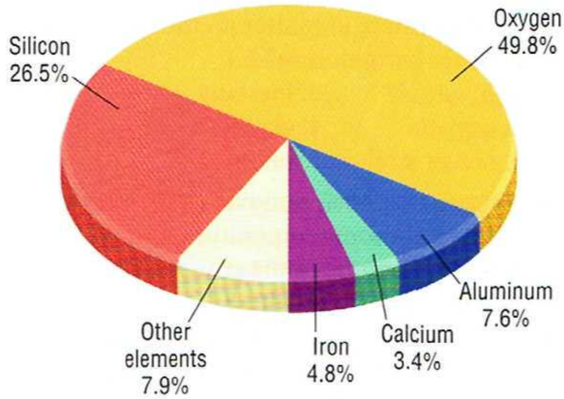
44. Choose the numbered term that best completes the second relationship.
   a. initial:final reactant: ______
   (1) product (3) matter
   (2) mixture (4) compound
   b. words:sentence elements: ______
   (1) reactant (3) compound
   (2) theory (4) substance
45. Compare the relationships among individual particles in the three states of matter.
46. Explain why this statement is false. "Because there is no change in composition during a physical change, the appearance of the substance will not change."

CONCEPT CHALLENGE

47. The mass of the elements iron and oxygen were measured in four samples of a rust-colored substance believed to be a compound. The amount of iron and oxygen found in each sample is shown on the graph.



   a. Do you think each sample is of the same compound? Explain.
   b. Another sample of similar material was found to contain 9.9 g of iron and 3.4 g of oxygen. Is this the same substance as the other four? Explain.
48. Five elements make up 97.9% of the mass of the human body. These elements are oxygen (64.8%), carbon (18.1%), hydrogen (10.0%), nitrogen (3.1%), and calcium (1.9%). Compare these data with those in the pie graph below, which shows the five most abundant elements by mass in Earth's crust, oceans, and atmosphere.



   a. Which elements are abundant in both Earth's surface and the human body?
   b. Which elements are abundant in Earth's surface but not in the human body?
   c. Would you expect the compounds making up the human body to be the same as or different from those found in rocks, water, and air? Explain your answer based on the evidence in the pie graph and the data above.
49. These questions refer to the substances in **Table 2.1**.
   a. How many of these substances are in the liquid state at 125 °C?
   b. Describe the physical properties of one of these substances that led you to the answer.
   c. The substances in the table are listed in order of increasing melting point. Propose another way that these data could be arranged.
50. Each day of your life you encounter some chemical changes that are helpful and some that are harmful. Cite three examples of each. For each example, list the indications that identified the change as chemical.

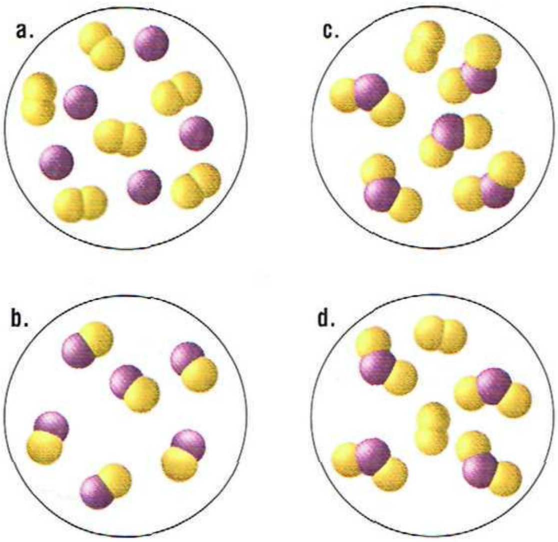
Chapter 2 STANDARDIZED TEST PREP

Select the choice that best answers each question or completes each statement.

1. Which of the following is *not* a chemical change?
   a. paper being shredded
   b. steel rusting
   c. charcoal burning
   d. a newspaper yellowing in the sun
2. Which phrase best describes an apple?
   a. heterogeneous mixture
   b. homogeneous compound
   c. heterogeneous substance
   d. homogeneous mixture
3. Which element is paired with the wrong symbol?
   a. sulfur, S **c.** nitrogen, N
   b. potassium, P **d.** silicon, Si
4. Which of these properties could *not* be used to distinguish between table salt and table sugar?
   a. boiling point **c.** density
   b. melting point **d.** color
5. The state of matter characterized by a definite volume and an indefinite shape is a
   a. solid. **c.** liquid.
   b. mixture. **d.** gas.

Use the atomic windows to answer question 6.

6. The species in window (a) react. Use the law of conservation of mass to determine which window best represents the reaction products.



The lettered choices below refer to questions 7–10. A lettered choice may be used once, more than once, or not at all.

(A) compound
(B) heterogeneous mixture
(C) element
(D) homogeneous mixture

Which description correctly identifies each of the following materials?

7. air
8. carbon monoxide
9. zinc
10. mushroom pizza

Use the data table to answer questions 11–14.

Mass of magnesium (g)	Mass of oxygen (g)	Mass of magnesium oxide (g)
5.0	3.3	8.3
6.5	(a)	10.8
13.6	9.0	(b)
(c)	12.5	31.5

11. Magnesium metal burns vigorously in oxygen to produce the compound magnesium oxide. Use the law of conservation of mass to identify the masses labeled (a), (b), and (c) in the table.
12. Use the data in the completed table to construct a graph with mass of magnesium on the *x*-axis and mass of magnesium oxide on the *y*-axis.
13. How many grams of magnesium oxide form when 8.0 g of magnesium are burned?
14. How many grams of magnesium and oxygen react to form 20.0 g of magnesium oxide?

Use the data table to answer questions 15–17.

Substance	Color	Melting point (°C)	Boiling point (°C)
bromine	red-brown	−7	59
chlorine	green-yellow	−101	−34
ethanol	colorless	−117	78
mercury	silver-white	−39	357
neon	colorless	−249	−246
sulfur	yellow	113	445
water	colorless	0	100

15. Which colorless substance is a liquid at −30 °C?
16. Which colorless substance is a gas at 60 °C?
17. Which substance is a solid at 7 °C?

THE PERIODIC TABLE: ORGANIZING THE ELEMENTS

objectives

- Describe the origin of the periodic table
- Identify the position of groups, periods, and the transition metals in the periodic table

key terms

- periodic table
- periods
- periodic law
- group
- representative elements
- metals
- alkali metals
- alkaline earth metals
- transition metals
- inner transition metals
- nonmetals
- halogens
- noble gases
- metalloids

How do you know where to find products in the supermarket? From your experience, you probably know that different types of products are arranged according to similar characteristics in aisles or sections of aisles. Such a classification structure makes finding and comparing products easy. **Is there a way of arranging more than 100 known elements?**

Development of the Periodic Table

About 70 elements had been discovered by the mid-1800s, but until the work of the Russian chemist Dmitri Mendeleev (1834–1907), no one had found a way to relate the elements in a systematic, logical way. Mendeleev listed the elements in columns in order of increasing atomic mass. He then arranged the columns so that the elements with the most similar properties were side by side. He thus constructed the first **periodic table,** an arrangement of the elements according to similarities in their properties. As you can see in **Figure 5.11,** Mendeleev left blank spaces in the table because there were no known elements with the appropriate properties and masses.

Mendeleev and others were able to predict the physical and chemical properties of the missing elements. Eventually these elements were discovered and were found to have properties similar to those predicted.

In 1913, Henry Moseley (1887–1915), a British physicist, determined the atomic number of the atoms of the elements. Moseley arranged the elements in a table by order of atomic number instead of atomic mass. That is the way the periodic table is arranged today.

			Ti = 50	Zr = 90	? = 180.
			V = 51	Nb = 94	Ta = 182.
			Cr = 52	Mo = 96	W = 186.
			Mn = 55	Rh = 104,4	Pt = 197,4
			Fe = 56	Ru = 104,4	Ir = 198.
			Ni = Co = 59	Pl = 106,6	Os = 199
H = 1			Cu = 63,4	Ag = 108	Hg = 200
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,5	Br = 80	I = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207.
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

Figure 5.11
A version of Dmitri Mendeleev's periodic table is shown here.

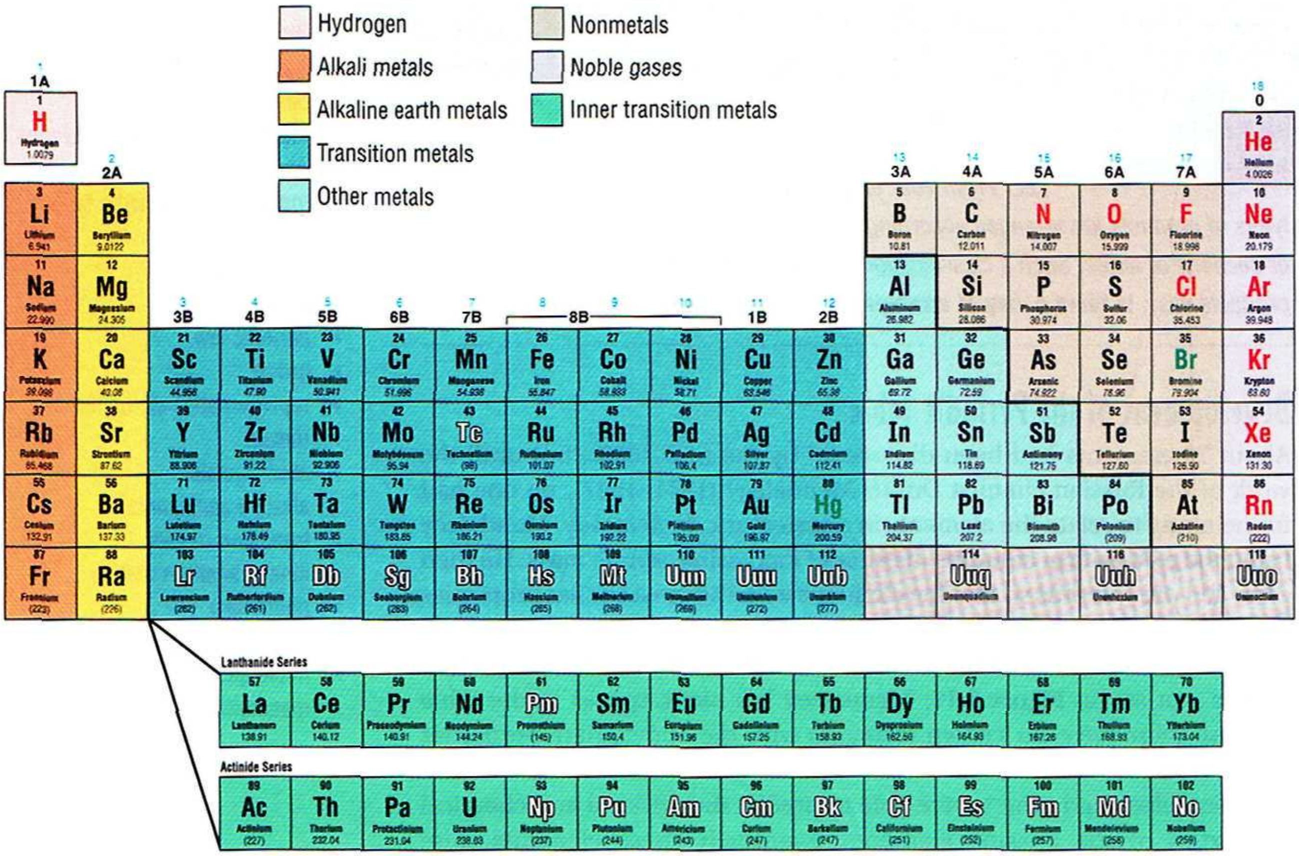


Figure 5.12
Elements are arranged in the modern periodic table in order of atomic number. The symbols are color coded according to the natural state of the elements: red for gases, black for solids, green for liquids (mercury and bromine), and white for elements that do not occur naturally.

The Modern Periodic Table

The most commonly used form of the modern periodic table, sometimes called the long form, is shown in **Figure 5.12.** Each element is identified by its symbol placed in a square. The atomic number of the element is shown centered above the symbol. The atomic mass and the name of the element are shown below the symbol. Notice that the elements are listed in order of increasing atomic number, from left to right and from top to bottom. Hydrogen (H), the lightest element, is in the top left corner. Helium (He), atomic number 2, is at the top right. Lithium (Li), atomic number 3, is at the left end of the second row.

The horizontal rows of the periodic table are called **periods.** There are seven periods. The number of elements per period ranges from 2 (hydrogen and helium) in period 1, to 32 in period 6. The properties of the elements within a period change as you move across it from element to element. The pattern of properties within a period repeats, however, when you move from one period to the next. This gives rise to the **periodic law:** When the elements are arranged in order of increasing atomic number, there is a periodic repetition of their physical and chemical properties. The arrangement of the elements into periods has an important consequence. Elements that have similar chemical and physical properties end up in the same column in the periodic table.

Each vertical column of elements in the periodic table is called a **group,** or family. The elements in any group of the periodic table have similar physical and chemical properties. Each group is identified by a number and the letter A or B. Look at the first column on the left. It includes the elements H, Li, Na, K, Rb, Cs, and Fr. This first column is designated Group 1A. Except for hydrogen, all of the Group 1A elements react vigorously, even explosively, with water. The next column to the right, Group 2A, starts with Be. Next comes Group 3A, toward the right of the table. The Group A elements are made up of Group 1A through Group 7A and Group 0 (the group at the far right). Group A elements are called the **representative elements** because they exhibit a wide range of both physical and chemical properties.

The representative elements can be divided into three broad classes. The first are **metals,** which have a high electrical conductivity and a high luster when clean. They are ductile (able to be drawn into wires) and malleable (able to be beaten into thin sheets). Except for hydrogen, the representative elements on the left side of the periodic table are metals. The Group 1A elements are called the **alkali metals,** and the Group 2A elements are called the **alkaline earth metals.** Most of the remaining elements that are not Group A elements are also metals. These include the **transition metals** and the **inner transition metals,** which together make up the Group B elements. Copper, silver, gold, and iron are familiar transition metals. The inner transition metals, which appear below the main body of the periodic table, are also called the rare-earth elements. Approximately 80% of all of the elements are metals. With one exception, all metals are solids at room temperature. **Figure 5.14** on page 126 shows the exception to this rule. What is the name, symbol, and physical state of this element?

Figure 5.13
The elements in the periodic table vary greatly in their properties.


Sodium emits bright yellow light during a flame test.


Potassium reacts violently with water.


Chromium, the principal element in chrome plating, resists corrosion.


Iodine exists as a solid and a vapor at 25°C.

Because of its malleability, silver is easily stamped into coins.

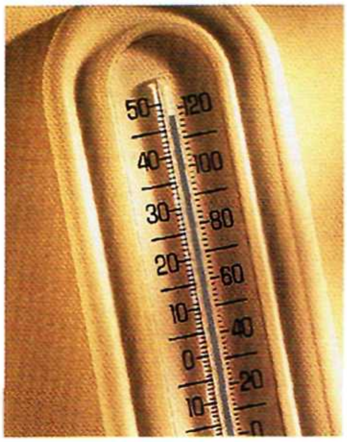


Figure 5.14
Mercury, a transition metal, is the only metallic element that is a liquid at room temperature. It is used in thermometers and barometers and as the electrical contact in a thermostat.

The nonmetals occupy the upper-right corner of the periodic table. **Nonmetals** are elements that are generally nonlustrous and that are generally poor conductors of electricity. Some of these elements, such as oxygen and chlorine, are gases at room temperature. Others, such as sulfur, shown in **Figure 5.15,** are brittle solids. One element, bromine, is a fuming dark-red liquid at room temperature. Two groups of nonmetals are given special names. The nonmetals of Group 7A are called the **halogens,** which include chlorine and bromine. The nonmetals of Group 0 are known as the **noble gases,** which are sometimes called the inert gases because they undergo few chemical reactions. The noble gas neon is used to fill the glass tubes of neon lights.

Notice the heavy stair-step line in **Figure 5.12.** This line divides the metals from the nonmetals. Most of the elements that border this line are **metalloids,** elements with properties that are intermediate between those of metals and nonmetals. Silicon and germanium are two important metalloids that are used in the manufacture of computer chips and solar cells.

Without the help of the periodic table, it would be quite difficult to learn and remember the chemical and physical properties of the more than 100 elements. Instead of memorizing their properties separately, you need only learn the general behavior and trends within the major groups. This gives you a useful working knowledge of the properties of most elements.

Figure 5.15
Sulfur is a low-melting point nonmetallic element that occurs as a crystalline solid or in the amorphous (formless) state. It is often mined through a process involving the pumping of hot water, which melts the sulfur. Sulfur is used primarily in the manufacture of sulfuric acid.

section 5.4 review

27. Describe how the periodic table was developed.
28. What criteria did Mendeleev use to construct his periodic table of the elements?
29. Relate group, period, and transition metals to the periodic table.
30. Identify each element as a metal, metalloid, or nonmetal.
    a. gold **b.** silicon **c.** manganese **d.** sulfur **e.** barium
31. Which of the elements listed in the preceding question are representative elements?
32. Name two elements that have properties similar to those of the element calcium.

Chem ASAP! Assessment 5.4 Check your understanding of the important ideas and concepts in Section 5.4.

ASK AN ARTIFACT FOR A DATE!

A human skeleton is discovered when construction begins on a new school. Is it the remains of someone who died within the past 200 years? Perhaps it is the remains of an early Native American who lived in the area 9000 years ago. An archaeologist is called to the site. She examines the skeleton and finds evidence that it may be very old. To determine its age, she uses a technique called radiometric dating.

Radiometric dating is based on two important facts: each element exists as more than one isotope, and some of these isotopes undergo radioactive decay. As you know, isotopes are atoms with the same number of protons and electrons but with different numbers of neutrons. Isotopes with an unstable ratio of protons and neutrons are radioactive. An atom of a radioactive isotope will emit radiation, changing into an atom of a different element. Although it is impossible to predict when a single atom of a radioactive isotope will decay, a large group of such atoms has a regular and predictable rate of decay. The amount of time it takes for half the atoms in a sample of a certain isotope to decay is called the half-life of that isotope.

When scientists want to date an artifact that was once part of a living organism, they often use a kind of radiometric dating called carbon-14 ($^{14}_{6}C$) dating. This method involves measuring the amount of the isotope carbon-14 in the artifact.

How is the amount of carbon-14 in an artifact related to its age? Carbon-14 is a radioactive isotope of carbon, with a half-life of 5730 years. It is present in small amounts in the environment, along with the two stable and more common isotopes of carbon, $^{12}_{6}C$ and $^{13}_{6}C$. The ratio of $^{14}_{6}C$ to the other carbon isotopes is relatively constant throughout the environment because $^{14}_{6}C$ is produced at a constant rate in the upper atmosphere by high-energy cosmic rays and is spread evenly throughout the biosphere. Living organisms all have the same ratio of $^{14}_{6}C$ to stable carbon in their bodies because they are constantly exchanging carbon with the environment.

Carbon-14 dating can give accurate ages of artifacts that are up to about 40 000 years old.

When an organism dies, however, it stops exchanging carbon with the environment. The radioactive $^{14}_{6}C$ atoms in the remains of the organism decay at the rate characteristic of $^{14}_{6}C$ without being replaced by new ones. Therefore, the ratio of $^{14}_{6}C$ to stable carbon in an organism begins to change in a regular, predictable way at the moment the organism dies.

To determine the age of once-living remains, a scientist can find the ratio of $^{14}_{6}C$ to stable carbon in the remains and compare it with the ratio that should have been in the organism when it was alive. If a once-living artifact contains half the $^{14}_{6}C$ of a living organism, for example, it must be about 5730 years old—the amount of time equal to one half-life of carbon-14.

Carbon-14 dating can give accurate ages of artifacts that are up to about 40 000 years old. When objects are much older than that, the amount of $^{14}_{6}C$ they contain is so small that the use of carbon-14 dating is impractical.

CHEMISTRY IN CAREERS

TAKE IT TO THE NET

Find out more about career opportunities:
www.phschool.com

CHEMICAL SPECIALIST

Local food service distributor seeks responsible self-motivated individ-

ARCHAEOLOGIST

Use carbon-14 dating and other chemical techniques to estimate the age and composition of artifacts.
See page 870.

CHEMIST NEEDED