2 Matter and Change

INSIDE:

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As a grilled cheese sandwich cooks, physical and chemical changes are taking place. Melting cheese is a physical change. Toasting bread is a chemical change.

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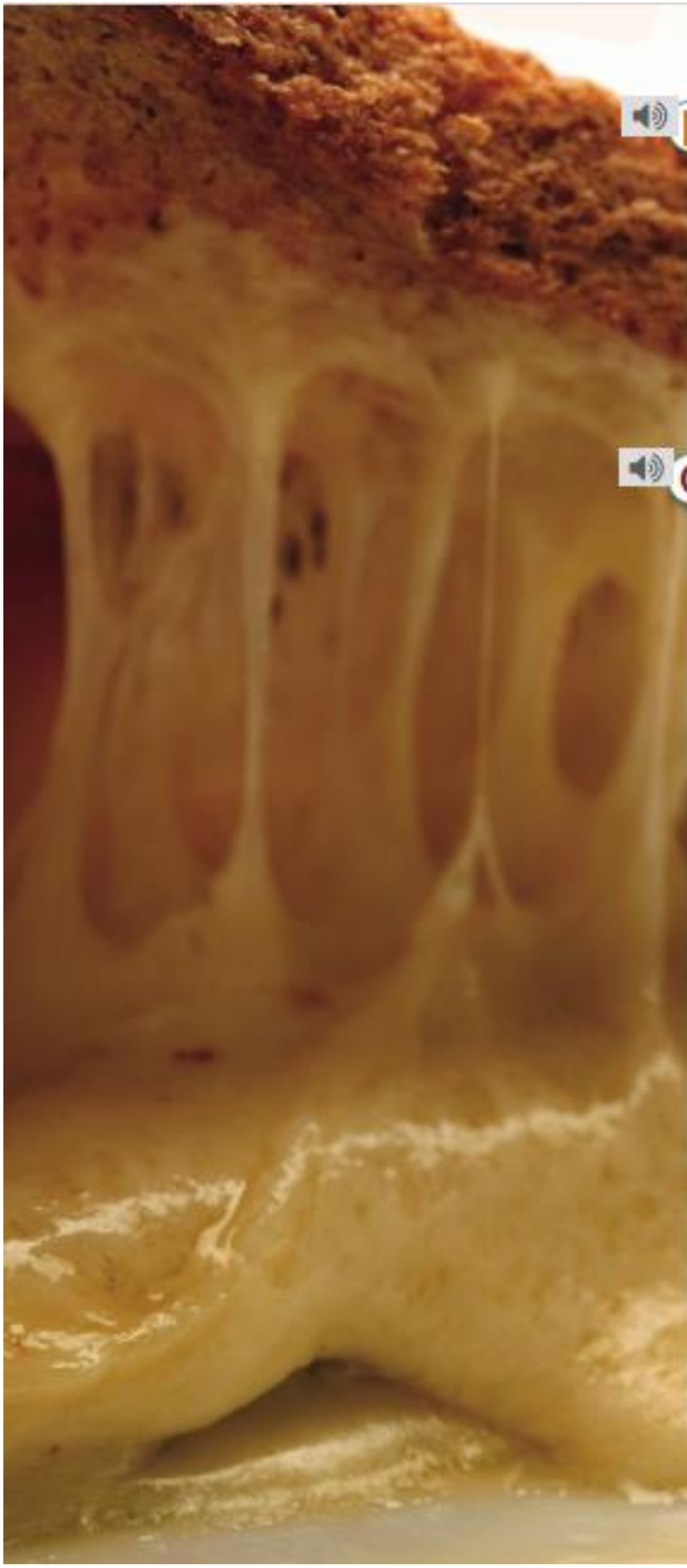

BIGIDEA

CHEMISTRY AS THE CENTRAL SCIENCE

Essential Questions:

1. *What properties are used to describe matter?*
2. *How can matter change its form?*

CHEMYSTERY

Which One Is Not Like the Others?

In Yellowstone National Park, there are more than 300 geysers. If you are able to witness a geyser erupting, you will see water and steam shooting out of the ground.

In Glacier National Park, the bottoms of glaciers go through melting and freezing cycles. These cycles produce valleys that are scoured into a U-shape and are flanked by steep sides of earth.

In Acadia National Park, the leaves on the deciduous trees change color each fall. The leaves go from green to red, orange, or yellow.

All three of these sights are amazing to see. They all result from changes. Are they physical or chemical changes? One of them is not like the others. But which one is different, and why?

► Connect to the **BIG**IDEA As you read about matter, think about how matter is altered by physical and chemical changes.

NATIONAL SCIENCE EDUCATION STANDARDS

A-1, B-2, B-3, E-2, G-3

2.1 Properties of Matter

CHEMISTRY & YOU

Q: *Why are windows made of glass?* When you think of a window, you probably think of something that you can look through. Most windows are made of glass and are transparent, meaning you can see through them. If you found a piece of broken glass on the ground, you would probably recognize it as glass. It is hard, yet easy to shatter, and it is heat resistant. In this lesson, you will learn how properties can be used to classify and identify matter.

Key Questions

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

Describing Matter

Why do all samples of a substance have the same intensive properties?

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 properties.

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 the basketball in Figure 2.1 is greater than the mass of the golf ball. 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. The volume of the basketball is greater than the volume of the golf ball. Mass and volume are both examples of extensive properties. An **extensive property** is a property that depends on the amount of matter in a sample.

Intensive Properties Basketballs may appear to be all the same. But, there are properties to consider when selecting a basketball besides mass and volume. The outer covering may be made of leather, rubber, or a synthetic composite. Each of these materials has different properties which make the basketballs suitable for different playing situations. For example, leather balls are suitable for indoor play but not outdoor play. Leather balls absorb water and dirt more than rubber balls. Absorbancy 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.

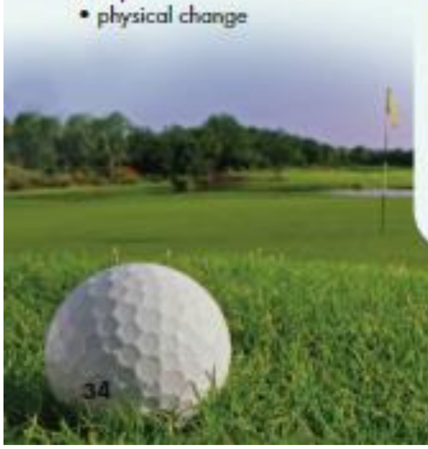

Figure 2.1 Extensive Properties
Golf balls and basketballs have different masses and different volumes.

Identifying a Substance Each object in Figure 2.2 has a different chemical makeup, or composition. The soda can is mainly aluminum. The watering can is mainly copper. Matter that has a uniform and definite composition is called a **substance.** Aluminum 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.**

Aluminum and copper have some properties in common, but there are differences besides their distinctive colors. Aluminum is highly reflective and is often used in silver paints. Pure copper can scratch the surface of pure aluminum because copper is harder than aluminum. Copper is better than aluminum as a conductor of heat or electric current. Copper and aluminum are both malleable, which means they can be hammered into sheets without breaking. 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 definitely not be water. Based on Table 2.1, it would likely be ethanol.

Figure 2.2 Aluminum and Copper
This soda can is made almost entirely of a thin sheet of aluminum. The watering can is made of copper, which has been hammered to give its textured appearance.
Analyze Data *Which of the properties listed in Table 2.1 could not be used to distinguish copper from aluminum?*

CHEMISTRY & YOU

Q: *Glass is often used to make windows, while copper is often used in electrical wires. What properties of glass make it a desirable material to use for windows?*

Interpret Data

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
Aluminum	Solid	Silver	660	2519
Sodium chloride	Solid	White	801	1413
Gold	Solid	Yellow	1064	2856
Copper	Solid	Reddish-yellow	1084	2562

Table 2.1 A substance can be described and identified by its physical properties.

a. Identify Which property can most easily distinguish chlorine from the other gases?

b. Identify A colorless liquid boils at 40°C. Is the substance water? Why or why not?

c. Calculate Which of the liquid substances has the highest melting point? The lowest boiling point?

d. Draw Conclusions Which of the properties would be the most helpful in identifying an unknown substance?

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States of Matter

What are three 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.

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.

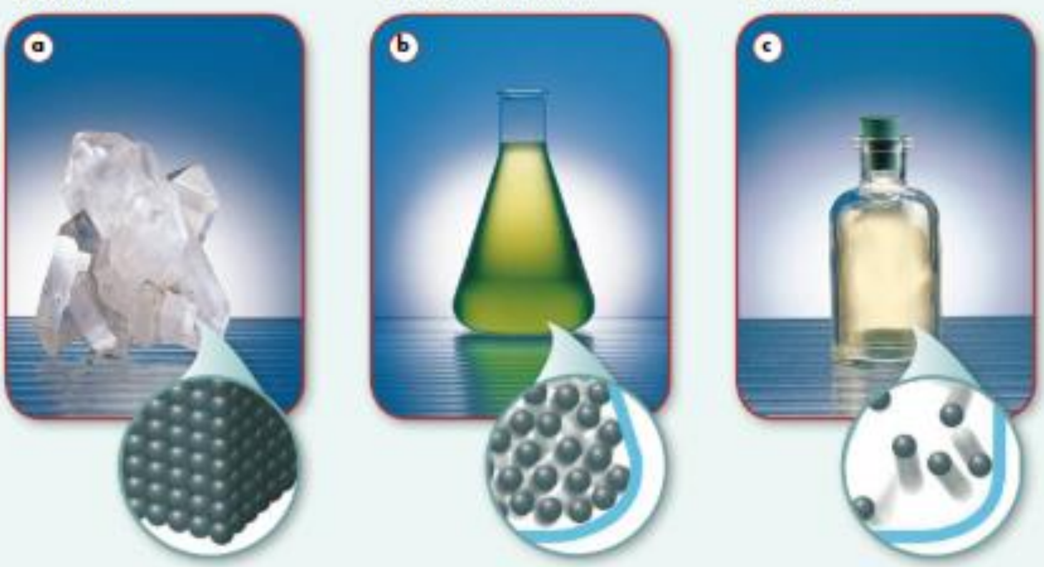
Figure 2.3
The arrangement of particles is different in solids, liquids, and gases.
Relate Cause and Effect *Use the arrangements of their particles to explain the general shape and volume of solids and gases.*

See states of matter animated online. KINETIC ART

Solid In a solid, the particles are packed closely together in a rigid arrangement.

Liquid In a liquid, the particles are close together, but they are free to flow past one another.

Gas In a gas, the particles are relatively far apart and can move freely.



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*.

Physical Changes

How can physical changes be classified?

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 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.

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

2.1 LessonCheck

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

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CHEMISTRY AS THE CENTRAL SCIENCE

9. How would understanding the properties of matter be helpful in other fields of study besides chemistry?

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2.2 Mixtures

CHEMISTRY & YOU

Q: *Why aren't there coffee grounds in a cup of coffee?* Coffee is often brewed by mixing hot water with ground coffee beans. But when people drink coffee, the grounds are usually not in their mug. In this lesson, you will learn how to classify and separate mixtures.

Key Questions

How can mixtures be classified?

How can mixtures be separated?

Vocabulary

- mixture
- heterogeneous mixture
- homogeneous mixture
- solution
- phase
- filtration
- distillation

Classifying Mixtures

How can mixtures be classified?

A salad bar, like the one in Figure 2.5, provides a range of items, such as lettuce, tomatoes, cheese, and green peppers. Customers choose which items to use in their salads and how much of each item to use. So each salad mixture has different types and amounts of components. 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
Salads Are Mixtures
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

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

Separating Mixtures

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, as shown in the diagram below.

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. Identify How did the appearance of the filter paper change during the procedure?

2. Analyze Data What evidence is there that green ink is a mixture?

3. Apply Concepts How could you use this procedure to identify an unknown type of green ink?

Heterogeneous Mixtures In chicken noodle soup, the ingredients in the soup are not evenly distributed throughout the mixture. There is likely to be different amounts of chicken and noodles in each spoonful. A mixture in which the composition is not uniform throughout is a **heterogeneous mixture.**

Homogeneous Mixtures The substances in the olive oil in Figure 2.6 are evenly distributed throughout the mixture. 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 a heterogeneous mixture with two layers, or phases. As shown in Figure 2.6, the oil phase floats on the water, or vinegar, phase.

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

Figure 2.7 Filtration
A filter is used to separate ground coffee beans from brewed coffee. This process is a type of filtration.

Separating Mixtures

How can mixtures be separated ?

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 coffee filter in Figure 2.7 can separate ground coffee beans from brewed coffee. The liquid brewed coffee passes through the paper filter, but the solid coffee grounds cannot pass through the filter. Filter paper used in a laboratory is similar to coffee filters. Filter paper is often placed in a funnel. Then the mixture is poured into the funnel. Solid particles that cannot pass through the filter remain in the funnel. The rest of the particles in solution pass through the filter paper. The process that separates a solid from the liquid in a heterogeneous mixture is called **filtration.**

CHEMISTRY & YOU

Q: *Brewing coffee is a mixture of ground coffee beans and water. What process is used to separate ground coffee beans from brewed coffee?*

Distillation Tap water is a homogeneous mixture of water and substances that are 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.

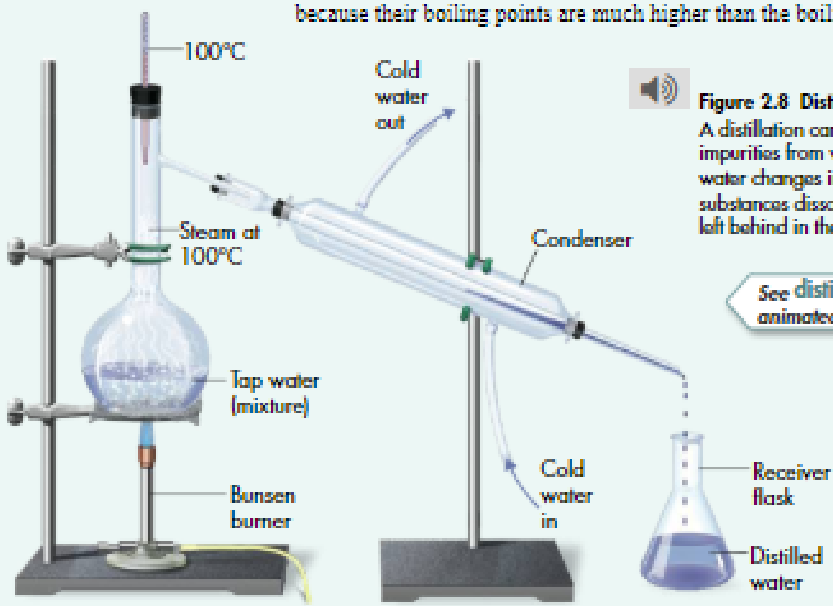

Figure 2.8 Distillation
A distillation can be used to remove impurities from water. As liquid water changes into water vapor, substances dissolved in the water are left behind in the distillation flask.

See distillation animated online. KINETIC ART

SampleProblem 2.1

Separating a Heterogeneous Mixture

How could a mixture of aluminum nails and iron nails be separated?

1 Analyze Identify the relevant concepts. In order to identify how to separate aluminum and iron nails, the properties of both aluminum and iron must be known.

2 Solve Apply concepts to this situation.

List the properties of each substance in the mixture.

Aluminum	Iron
• metal	• metal
• gray color	• gray color
• doesn't dissolve in water	• doesn't dissolve in water
• not attracted to magnet	• attracted to magnet

Identify a property that can be used to separate different substances from each other.

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.

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

11. 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?

2.2 LessonCheck

12. **Identify** How are mixtures classified?

13. **List** What type of properties can be used to separate mixtures?

14. **Explain** Explain the term *phase* as it relates to homogeneous and heterogeneous mixtures.

15. **Classify** 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

16. **Compare and Contrast** How are a substance and a solution similar? How are they different?

17. **Apply Concepts** In general, when would you use filtration to separate a mixture? When would you use distillation to separate a mixture?

18. **Explain** Describe a procedure that could be used to separate a mixture of sand and table salt.

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CHEMISTRY AS THE CENTRAL SCIENCE

19. Give three examples of when you have separated mixtures at home.

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2.3 Elements and Compounds

CHEMISTRY & YOU

Q: *Why does burned toast taste so bad?* Bread that is toasted to a nice golden brown makes for a tasty addition to breakfast. But most people would agree that bread that is cooked so long that it is burned and black is not tasty.

Key Questions

How are elements and compounds different?

How can substances and mixtures be distinguished?

What do chemists use to represent elements and compounds?

Why is a periodic table useful?

Vocabulary

- element
- compound
- chemical change
- chemical symbol
- periodic table
- period
- group

Distinguishing Elements and Compounds

How are elements and compounds different?

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. Sometimes sucrose is called 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.

Figure 2.9 Chemical Changes 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.

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?

There is no chemical process that will break down carbon into simpler substances because carbon is an element. Heat 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)

CHEMISTRY & YOU

Q: *What happens to the compounds in bread when it is overcooked that causes the changes to the taste of the bread?*

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.

Figure 2.10 Properties of Compounds and Their Elements
Compounds and the elements from which they form have different properties. The elements sodium and chlorine have different properties from each other and from the compound sodium chloride.
Observe ***Based on the photographs, describe two physical properties of sodium and two of chlorine.***

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.

Chlorine is used to make compounds that kill harmful organisms in swimming pools.

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

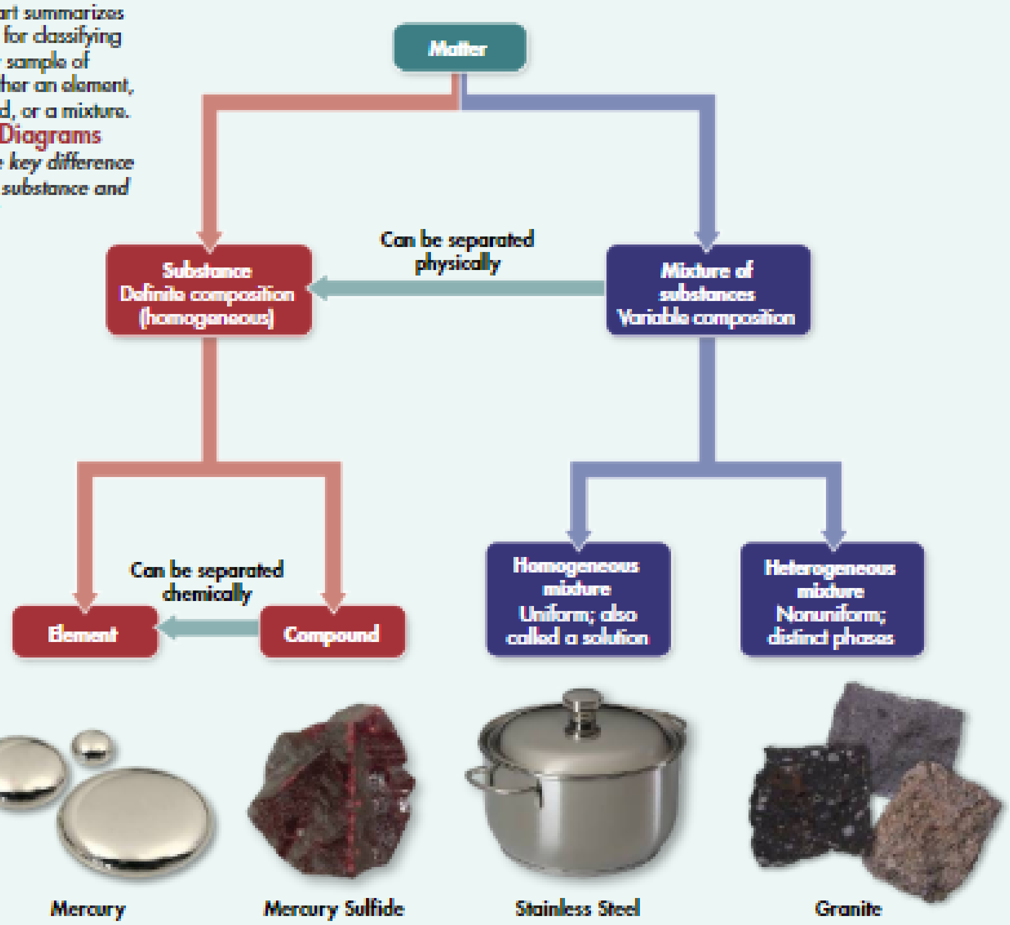
Distinguishing Substances and Mixtures

How can substances and mixtures be distinguished?

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, or 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 Element, Compound, or Mixture? The flowchart summarizes the process for classifying matter. Any sample of matter is either an element, a compound, or a mixture. **Interpret Diagrams** *What is the key difference between a substance and a solution?*



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Sample Problem 2.2

Classifying Materials

When a certain blue-green solid 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. 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.

A compound is made of two or more elements that are chemically combined.

List the known facts and relevant concepts.
- A blue-green solid is heated.

Determine if the substances are elements or compounds.
- A colorless gas and a black solid appear.

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 and the black solid are elements or compounds.

20. 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?

21. 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?

Symbols and Formulas

What do chemists use to represent elements and compounds?

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. For thousands of years, alchemists used symbols, such as the ones in Figure 2.12, to represent elements. 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 Element Symbols 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.

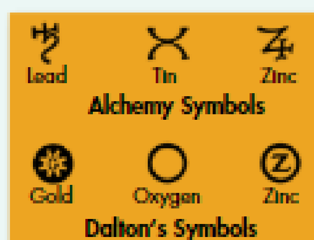


Table 2.2
Symbols and Latin Names for Some Elements

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*

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 for which 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 tell you how many of each type of element are 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.

The Periodic Table—A Preview

Why is a periodic table useful?

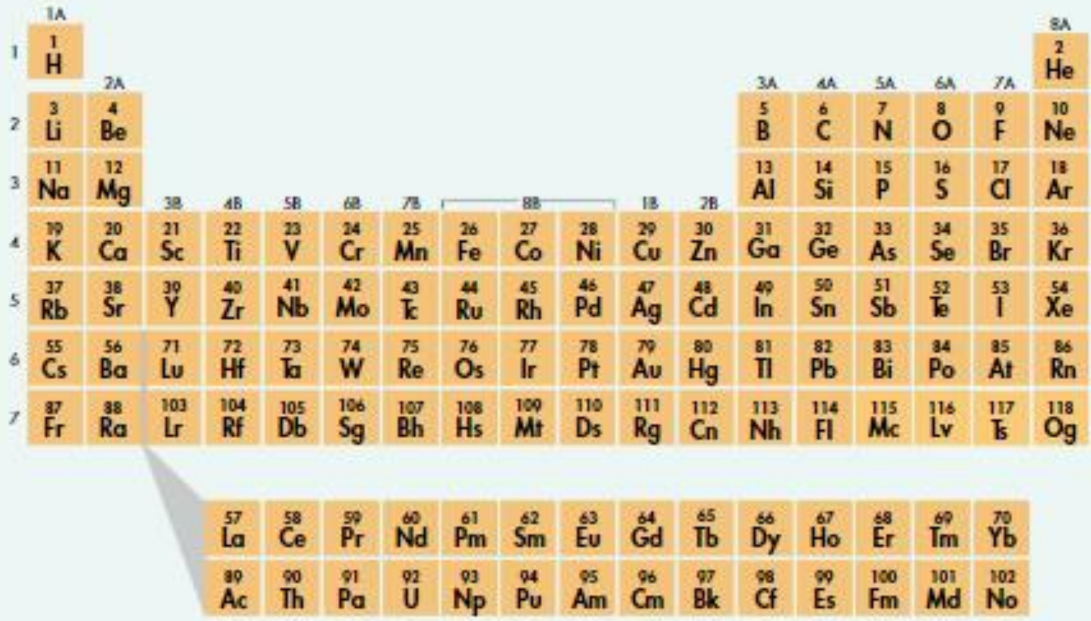
All the known elements are organized in a special table called the periodic table. A **periodic table** is an arrangement of elements in which the elements are separated into groups based on a set of repeating properties. **The periodic table allows you to easily compare the properties of one element (or a group of elements) to another element (or group of elements).**

Figure 2.13 shows the most commonly used form of the modern periodic table, sometimes called the long form. Each element is identified by its symbol placed in a square. The elements are listed in order from left to right and top to bottom by atomic number, a number that is unique to each element. The atomic number of the element is shown centered above the symbol. You will learn more about atomic numbers in Chapter 4. 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.

Each horizontal row of the periodic table is called a **period**. There are seven periods in the periodic table. The number of elements per period ranges from 2 (hydrogen and helium) in Period 1 to 32 in Period 6. Within a period, the properties of the elements vary as you move across the period. This pattern of properties then repeats as you move to the next period.

Each vertical column of the periodic table is called a **group**, or family. Elements within a group have similar chemical and physical properties. Note that each group is identified by a number and the letter A or B. For example, Group 2A contains the elements beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and radium (Ra). You will learn more about specific trends in the periodic table in Chapter 6.

Figure 2.13 The Periodic Table
Elements are arranged in the modern periodic table in order of atomic number.
Interpret Diagrams *How many elements are in Period 2? In Group 2A?*



2.3 LessonCheck

22. **Compare** How is a compound different from an element?

23. **Compare** How can you distinguish a substance from a mixture?

24. **Identify** What are chemical symbols and chemical formulas used for?

25. **Explain** What makes the periodic table such a useful tool?

26. **Identify** Name two methods that can be used to break down compounds into simpler substances.

27. **Classify** Classify each of these samples of matter as an element, a compound, or a mixture.
a. table sugar **c.** cough syrup
b. tap water **d.** nitrogen

28. **Identify** Write the chemical symbol for each of the following elements:
a. lead **c.** silver **e.** hydrogen
b. oxygen **d.** sodium **f.** aluminum

29. **Identify** Name the chemical elements represented by the following symbols:
a. C **c.** K **e.** Fe
b. Ca **d.** Au **f.** Cu

30. **Identify** 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?

31. **Identify** Name two elements that have properties similar to those of the element calcium (Ca).

2.4 Chemical Reactions

CHEMISTRY & YOU

Q: *What happened to the match?* Matches are often used to light candles on a cake. A match is usually lit at the tip and then burns down the match. So you better be quick, or your fingers will be burned by the lit match. A lit match is different than an unlit match. In this lesson, you will learn to recognize whether the burning match is a chemical change or physical change.

Key Questions

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 SUPPORT

Build Study Skills: Preview Visuals Before you start reading the lesson, preview the visuals in Figure 2.16. Then write two questions you have about the visuals. After you finish reading, answer your questions.

Chemical Changes

What always happens during a chemical change?

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 2.14 compares a physical change and a chemical change that can occur in a sample of charcoal. When charcoal is broken into smaller pieces, the change is a physical change. The substances present before the change are the same substances present after the change, although the charcoal pieces are not as large. Recall that during a physical change, the composition of matter never changes. **During a chemical change, the composition of matter always changes.** When the charcoal is heated and burned, a chemical change occurs. The substances in charcoal react with oxygen in the air to form other substances.

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 burning of charcoal, carbon and oxygen are the main reactants, and carbon dioxide is the main product.

Figure 2.14
Physical and Chemical Changes
Charcoal is used as a fuel in charcoal grills. **a.** Breaking the charcoal into smaller pieces is a physical change. **b.** Burning the charcoal is a chemical change.

Figure 2.15 Chemical Change
Clues to chemical change often have practical applications.

Learn more about physical and chemical changes online.

Production of a Gas
Bubbles of carbon dioxide gas form when an antacid tablet is dropped into a glass of water.

Color Change
When a test strip is dipped in a solution, the color change is used to determine the pH of the solution.

Formation of a Precipitate
One step in the production of cheese is a reaction that causes milk to separate into solid curds and liquid whey.

Recognizing Chemical Changes

What are four possible clues that a chemical change has taken place?

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 chemically 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 change color and 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 produced because a gas is released during the 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 2.15 shows examples of practical situations in which different clues to chemical change are visible.

CHEMISTRY & YOU

Q: *Are the changes that happen to a burning match chemical changes or physical changes? How do you know?*

Conservation of Mass

How are the mass of the reactants and the mass of the products of a chemical reaction related?

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 2.16.

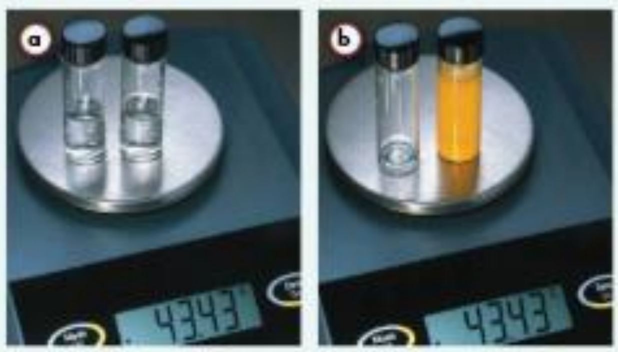


Figure 2.16
Conservation of Mass
When the liquids in **a.** are mixed, they react. The products are shown in **b.** None of the products are gases.
Analyze Data *How do you know that a reaction took place and that mass was conserved during the reaction?*

2.4 LessonCheck

32. Explain How does a chemical change affect the composition of matter?

33. List Name four possible clues that a chemical change has taken place.

34. Compare In a chemical reaction, how does the mass of the reactants compare with the mass of the products?

35. Compare What is the main difference between physical changes and chemical changes?

36. Classify 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.

37. Explain According to the law of conservation of mass, when is mass conserved?

38. Calculate 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?

50 Chapter 2 • Lesson 4

2 Study Guide

BIGIDEA
CHEMISTRY AS THE CENTRAL SCIENCE

Physical properties, such as melting point and boiling point, and chemical properties, such as whether a substance will corrode or burn, are used to describe matter. Matter may be made of elements or compounds. Elements and compounds are pure substances but can be physically combined to make heterogenous or homogeneous mixtures. These different forms of matter may undergo physical or chemical changes.

2.1 Properties of Matter

Every sample of a given substance has identical intensive properties because every sample has the same composition.

Three states of matter are solid, liquid, and gas.

Physical changes can be classified as reversible or irreversible.

- mass (34)
- volume (34)
- extensive property (34)
- intensive property (34)
- substance (35)
- physical property (35)
- solid (36)
- liquid (36)
- gas (37)
- vapor (37)
- physical change (37)

2.2 Mixtures

Mixtures can be classified as heterogeneous mixtures or as homogeneous mixtures, based on the distribution of their components.

Differences in physical properties can be used to separate mixtures.

- mixture (38)
- heterogeneous mixture (39)
- homogeneous mixture (39)
- solution (39)
- phase (39)
- filtration (40)
- distillation (40)

2.3 Elements and Compounds

Compounds can be broken down into simpler substances by chemical means, but elements cannot.

If the composition of a material is fixed, the material is a substance. If the composition may vary, the material is a mixture.

Chemists use chemical symbols to represent elements, and chemical formulas to represent compounds.

The periodic table allows you to easily compare the properties of one element (or a group of elements) to another element (or group of elements).

- element (42)
- compound (42)
- chemical change (43)
- chemical symbol (45)
- periodic table (46)
- period (46)
- group (47)

2.4 Chemical Reactions

During a chemical change, the composition of matter always changes.

Four 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.

During any chemical reaction, the mass of the products is always equal to the mass of the reactants.

- chemical property (48)
- chemical reaction (48)
- reactant (48)
- product (48)
- precipitate (49)
- law of conservation of mass (50)

2 Assessment

* Solutions appear in Appendix E

Lesson by Lesson

2.1 Properties of Matter

39. Describe the difference between an extensive property and an intensive property and give an example of each.

40. List three physical properties of copper.

41. Name two physical properties that could be used to distinguish between water and ethanol.

*42. Name one physical property that could not be used to distinguish chlorine from oxygen.

43. What is the physical state of each of these materials at room temperature?
    a. gold
    b. gasoline
    c. oxygen
    d. neon
    e. olive oil
    f. sulfur
    g. mercury

*44. 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.

45. Compare the arrangements of individual particles in solids, liquids, and gases.

46. 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?

*47. Explain why sharpening a pencil is a different type of physical change than freezing water to make ice cubes.

2.2 Mixtures

48. What is the difference between homogeneous mixtures and heterogeneous mixtures?

49. How many phases does a solution have? Explain your answer.

*50. Classify each of the following as a homogeneous or heterogeneous mixture.
    a. chocolate-chip ice cream
    b. green ink
    c. cake batter
    d. cooking oil
    e. granite rock
    f. salt water
    g. paint
    h. a silver ring

51. What is the goal of a distillation? Describe briefly how this goal is accomplished.

2.3 Elements and Compounds

52. How could you distinguish an element from a compound?

*53. Classify the following materials as an element, compound, or mixture. Give reasons for your answers.
    a. table salt (NaCl)
    b. salt water
    c. sodium (Na)

54. 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

55. 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)

56. 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.

*57. What does the formula H_2O tell you about the composition of water?