Section 3.4 Elements and Compounds

Objectives

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

Vocabulary

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

To this point you've examined many of the properties of matter. You've also learned how scientists have organized, classified, and described matter by arranging it into various subcategories of components. But there remains another fundamental level of classification of matter: the classification of pure substances as elements or compounds.

Elements

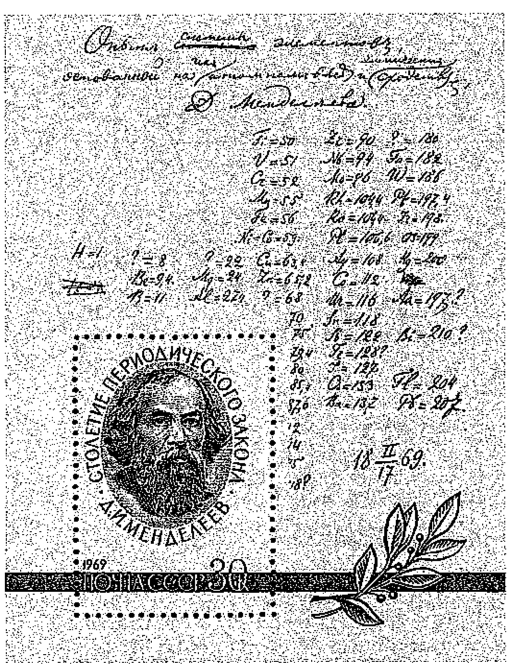
Recall that earlier in this chapter you considered the diversity of your surroundings in terms of matter. Although the diversity is astounding, in reality all matter can be broken down into a relatively small number of basic building blocks called elements. An **element** is a pure substance that cannot be separated into simpler substances by physical or chemical means. On Earth, 91 elements occur naturally. Copper, oxygen, and gold are examples of naturally occurring elements. There are also several elements that do not exist naturally but have been developed by scientists.

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

The 91 naturally occurring elements are not equally abundant. For example, hydrogen is estimated to make up approximately 75% of the mass of the universe. Oxygen and silicon together comprise almost 75% of the mass of Earth's crust, while oxygen, carbon, and hydrogen account for more than 90% of the human body. Francium, on the other hand, is one of the least abundant naturally occurring elements. It is estimated that there is probably less than 20 grams of francium dispersed throughout Earth's crust. To put that into perspective, the total mass of francium is approximately equal to the mass of your pencil or pen.

Figure 3-16

Although many early scientists have contributed to the modern organization of the elements, Mendeleev's system of rows and columns was a revolutionary advancement.



A first look at the periodic table As many new elements were being discovered in the early nineteenth century, chemists began to see patterns of similarities in the chemical and physical properties of particular sets of elements. Several schemes for organizing the elements on the basis of these similarities were proposed, with varying degrees of success. In 1869, the Russian chemist Dmitri Mendeleev made a significant contribution to the effort. Mendeleev devised the chart shown in **Figure 3-16**, which organized all of the elements that were known at the time into rows and columns based on their similarities and their masses. Mendeleev's organizational table was the first version of what has been further developed into the **periodic table** of elements. The periodic table organizes the elements into a grid of horizontal rows called periods and vertical columns called groups or families. Elements in the same group have similar chemical and physical properties. The table is called "periodic" because the pattern of similar properties repeats as you move from period to period.

One of the brilliant aspects of Mendeleev's original table was that its structure could accommodate elements that were not known at the time. Notice the blank spots in Mendeleev's table. By analyzing the similarities among the elements and their pattern of repetition, Mendeleev was able to predict the properties of elements that were yet to be discovered.

In most cases, Mendeleev's predictions (and the blanks in the table) closely matched the characteristics of new elements as they were discovered. **Figure 3-18** on pages 72–73 shows samples of the elements in their arrangement in the periodic table. The standard modern version of the periodic table includes more than 100 elements. You'll study the periodic table in greater detail later in this textbook. In fact, the periodic table remains a dynamic tool as scientists continue to discover new elements.

Compounds

Take a moment to recall what you have learned about the organization of matter, using **Figure 3-17** as a guide. You know that matter is classified as pure substances and mixtures. As you learned in the previous section, mixtures can be homogeneous or heterogeneous. You also know that elements are pure substances that cannot be separated into simpler substances. There is yet another classification of pure substances—compounds. A **compound** is a combination of two or more different elements that are combined chemically. Most of the substances that you are familiar with and, in fact, much of the matter of the universe are compounds. Water, table salt, table sugar, and aspirin are examples of common compounds.

Today, there are approximately 10 million known compounds, and new compounds continue to be developed and discovered at the rate of about 100 000 per year. Can you recall some of the medicinal compounds that have made headlines in recent years? There appears to be no limit to the number of compounds that can be made or that will be discovered. Considering this virtually limitless potential, several organizations have assumed the task of collecting data and indexing the known chemical compounds. These organizations maintain huge databases that allow researchers to access information on existing compounds. The databases and retrieval tools enable scientists to build the body of chemical knowledge in an efficient manner.

The chemical symbols of the periodic table make it easy to write the formulas for chemical compounds. For example, table salt, or sodium chloride, is composed of one part sodium (Na) and one part chlorine (Cl), and its chemical formula is NaCl. Water is composed of two parts hydrogen (H) to one part oxygen (O), and its formula is H_2O.

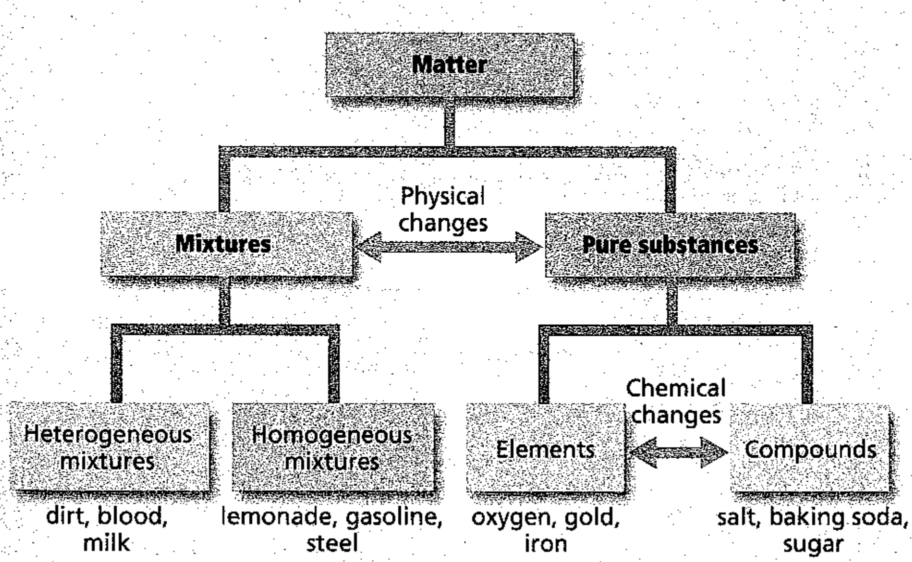


Figure 3-17

The concept of matter is far-reaching and can be overwhelming. But, when broken down as shown here, it becomes clear how elements, compounds, substances, and mixtures define all matter.

Mixtures of Matter

Objectives

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

Vocabulary

mixture
heterogeneous mixture
homogeneous mixture
solution
filtration
distillation
crystallization
chromatography

When scientists speak of the composition of matter, they are referring to the kinds and amounts of components of which the matter is made. On the basis of composition alone, all matter can be classified into two broad categories: substances or mixtures. You have already learned that a pure substance is a form of matter with a uniform and unchanging composition. You also know that the intensive properties of pure substances do not change, regardless of the physical state or amount of the substance. But what is the result when two or more substances are combined?

Mixtures

A **mixture** is a combination of two or more pure substances in which each pure substance retains its individual chemical properties. The composition of mixtures is variable, and the number of mixtures that can be created by combining substances is infinite. Although much of the focus of chemistry is the behavior of substances, it is important to remember that most everyday matter occurs as mixtures. Substances tend naturally to mix; it is difficult to keep things pure.

Two mixtures, sand and water, and table salt and water, are shown in **Figure 3-12a**. You know water to be a colorless liquid. Sand is a grainy solid that does not dissolve in water. When sand and water are mixed, the two substances are in contact, yet each substance retains its properties. The sand and water have not reacted. Just by looking at the sand–water mixture in beaker A, it is easy to see each separate substance. Some mixtures, however, may not look like mixtures at all. The mixture of table salt and water in the beaker labeled B is colorless and appears the same as pure water. How can you determine if it is a mixture? If you were to boil away the water, you would see a white residue. That residue, shown in **Figure 13-12b,** is the salt. Thus, the colorless mixture actually contained two separate substances. The salt and the water physically mixed but did not react and were separated by the physical method of boiling.

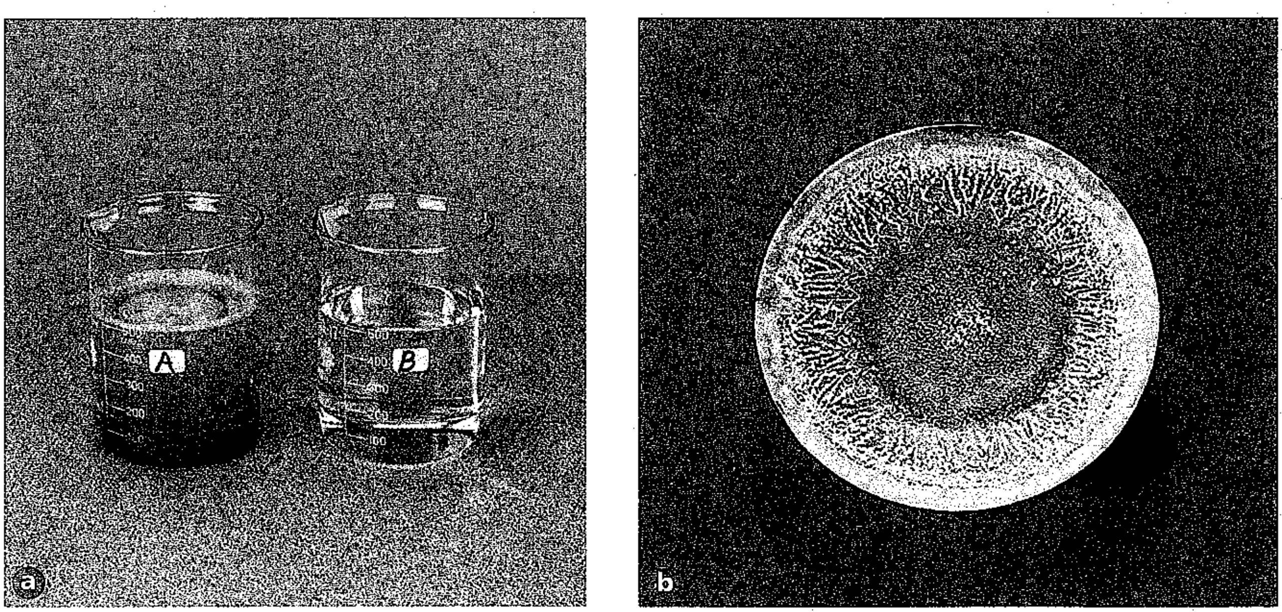


Figure 3-12

ⓐ The components of the sand and water mixture (left) are obvious, whereas the components of the table salt and water mixture (right) are not.
ⓑ The salt component becomes obvious when the mixture is boiled.

Types of mixtures The combinations of pure substances shown in **Figure 3-12** are indeed both mixtures, despite their obvious visual differences. Can you think of some way to further define mixtures? Mixtures themselves are classified as either heterogeneous or homogeneous. A **heterogeneous mixture** is one that does not blend smoothly throughout and in which the individual substances remain distinct. The sand and water mixture is an example of a heterogeneous mixture. Suppose you draw a drop from the top of the mixture using an eyedropper. The drop would be almost completely water. If you draw a second drop from the bottom of the mixture, that drop would contain mostly sand. Thus the composition of the sand–water mixture is not uniform—the substances have not blended smoothly and the two substances of the mixture (sand on the bottom and water on the top) remain distinct. In another example, fresh-squeezed orange juice is a mixture of juice and pulp. The pulp component floats on top of the juice component. Is your favorite pizza a mixture? The answer is yes when you consider that the pizza is a combination of distinct areas of dough, sauce, cheese, and toppings. We can therefore say that the existence of two or more distinct areas indicates a heterogeneous mixture.

A **homogeneous mixture** has constant composition throughout; it always has a single phase. Let's examine the salt–water mixture using the eyedropper. A drop of the mixture from the top of the beaker has the same composition as a drop from the bottom of the beaker. In fact, every drop of the mixture contains the same relative amounts of salt and water.

Homogeneous mixtures are also referred to as **solutions**. You are probably most familiar with solutions in a liquid form, such as cough suppressant medicine and lemonade, but solutions may contain solids, liquids, or gases. **Table 3-3** lists the various types of solution systems and gives an example of each. Solutions are very important in chemistry, and, in fact, this textbook devotes an entire chapter to the study of solutions.

The solid–solid solution known as steel is called an alloy. An alloy is a homogeneous mixture of metals, or a mixture of a metal and a nonmetal in which the metal substance is the major component. The U.S. Mint's golden dollar coin, shown in **Figure 3-13**, uses a metal alloy composed of 77% copper, 12% zinc, 7% manganese, and 4% nickel surrounding a copper core. Alloys are also used in spacecraft and automobiles. What might be the benefit of using alloys for these applications? Manufacturers combine the properties of various metals in an alloy to achieve greater strength and durability of their products.

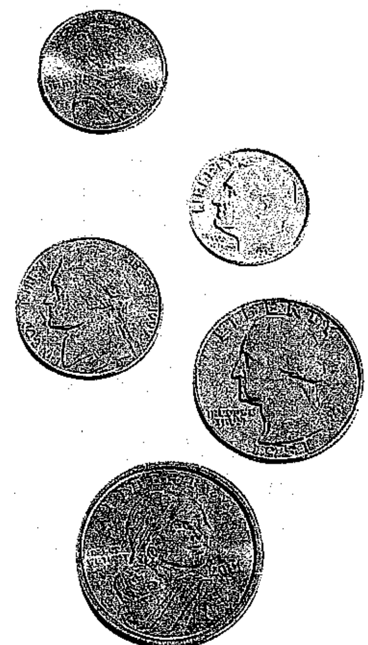


Figure 3-13

Coins issued by the U.S. Mint are metal alloys. The combination of multiple metals gives the coins specific properties such as color, weight, and durability.

Table 3-3

Types of Solution Systems	
System	**Example**
Gas–gas	Air is primarily a mixture of nitrogen, oxygen, and argon gases.
Gas–liquid	Carbonated beverages contain carbon dioxide gas in solution.
Liquid–gas	Moist air contains water droplets in air (which is a mixture of gases).
Liquid–liquid	Vinegar contains acetic acid in water.
Solid–liquid	Sweetened powder drink contains sugar and other solid ingredients in water.
Solid–solid	Steel is an alloy of iron containing carbon.

DISCOVERY LAB

Observing Chemical Change

Consider the metal objects that are part of the everyday world. A mailbox, for example, stands outside day in and day out, without seeming to change. Under what conditions does metal exhibit chemical change?

Safety Precautions

Always wear eye goggles, gloves, and an apron when experimenting with chemicals. Use caution when handling an open flame.

Materials

large test tube
test-tube holder or rack
10 mL HCl
zinc metal
wood splint
match or burner

Procedure

1. Place a piece of zinc metal in a large test tube.
2. Add approximately 10 mL of 3*M* hydrochloric acid (HCl) to the test tube. Record your observations.
   CAUTION: *HCl causes burns and hazardous fumes.*
3. When the zinc and HCl have reacted for approximately 1 min, bring a lighted, glowing wood splint to the mouth of the test tube. **CAUTION:** *Be sure the test tube is facing away from your face when the splint is brought near.* Again record your observations.

Analysis

What may have caused the dynamic reaction you observed in step 3? Did you expect this reaction? Explain.

Section 3.1 Properties of Matter

Objectives

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

Vocabulary

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

Imagine yourself scuba diving through a complex biological ecosystem such as a coral reef. What kinds of things fill your imagination? Regardless of what you envision, there is only one answer—you see matter. The diversity of matter in the world and in the universe is astounding. From pepperoni pizzas to supernovas, it's all matter. If we are to understand this diversity, we must start with a way of organizing and describing matter.

Substances

Recall from Chapter 1 that chemistry is the study of matter, and matter is anything that has mass and takes up space. Everything around you is matter; including things such as air and microbes, which you cannot see. For example, table salt is a simple type of matter that you are probably familiar with. Table salt has a unique and unchanging chemical composition. It is always 100% sodium chloride and its composition does not change from one sample to another. Matter that has a uniform and unchanging composition is called a **substance**, also known as a pure substance. Table salt is a substance. Another example of a pure substance is water. Water is always composed of hydrogen and oxygen. Seawater, on the other hand, is not a substance because samples taken from different locations will probably have

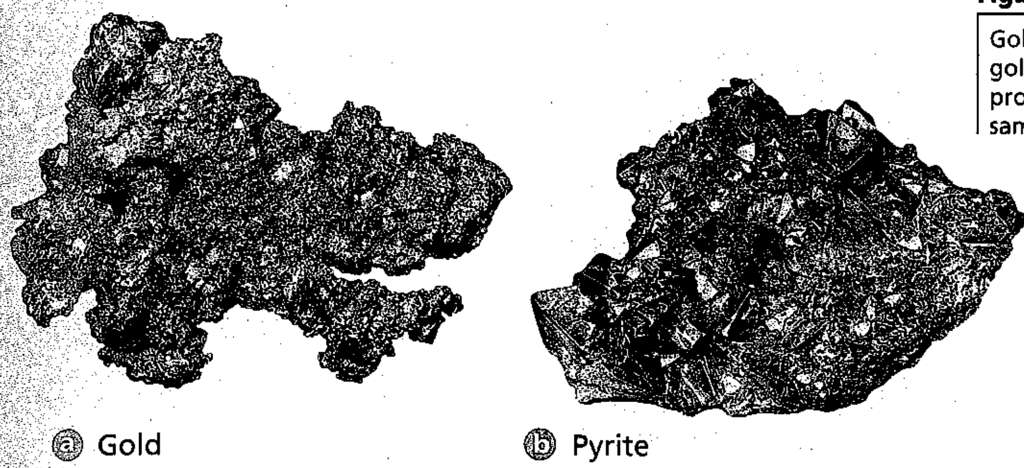


Figure 3-2

Gold ⓐ and pyrite, or "fool's gold" ⓑ, have similar physical properties but are different samples of matter.

mineral pyrite, often called "fool's gold," which looks very similar to actual gold nuggets. Such errors in identification based on the intensive property of appearance fooled many miners into falsely thinking they had struck it rich!

Chemical Properties of Matter

Some properties of a substance are not obvious unless the substance has changed composition as a result of its contact with other substances or the application of thermal or electrical energy. The ability of a substance to combine with or change into one or more other substances is called a **chemical property**. The ability of iron to form rust when combined with air is an example of a chemical property of iron. Similarly, the inability of a substance to change into another substance is also a chemical property. For example, when iron is placed in nitrogen gas at room temperature, no chemical change occurs. The fact that iron does not undergo a change in the presence of nitrogen is another chemical property of iron.

Observing Properties of Matter

Every substance has its own unique set of physical and chemical properties. **Table 3-2** lists several of these properties of copper. **Figure 3-3** shows physical and chemical properties of copper. What physical and chemical properties are evident in these photos?

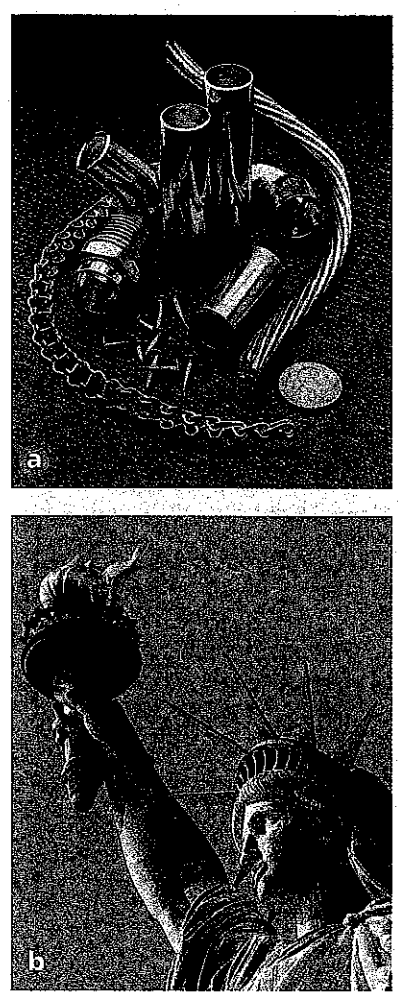
Table 3-2

Properties of Copper

Physical properties	Chemical properties
• Reddish brown, shiny • Easily shaped into sheets (malleable) and drawn into wires (ductile) • Good conductor of heat and electricity • Density = 8.92 g/cm^3 • Melting point = 1085°C • Boiling point = 2570°C	• Forms green copper carbonate compound when in contact with moist air • Forms new substances when combined with nitric acid and sulfuric acid • Forms a deep blue solution when in contact with ammonia

Figure 3-3

These photos illustrate some of the physical and chemical properties of copper as it exists in the form of hardware ⓐ and the Statue of Liberty ⓑ.



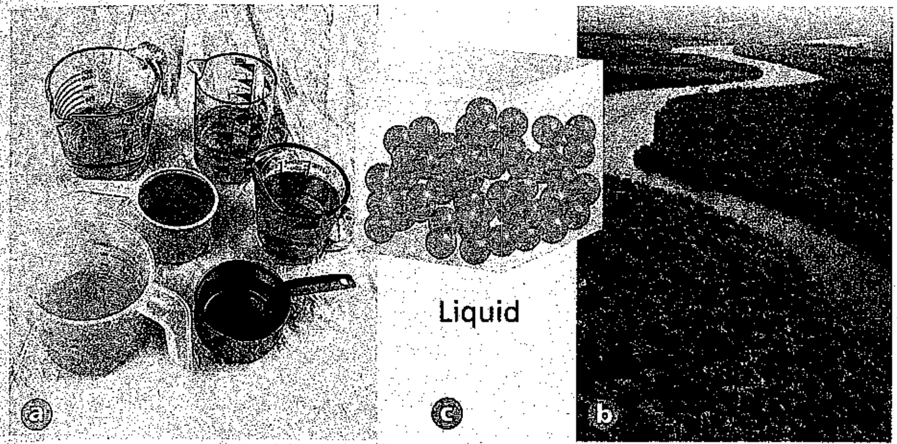


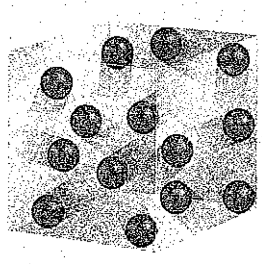
Figure 3-5

ⓐ Despite having different shapes, each of these measuring cups holds the same volume of liquid.
ⓑ River water flows to fit within the boundaries of its banks, regardless of the curves along its path.
ⓒ Molecules in a liquid are closely packed but can still move relatively freely.

are able to move past each other. This allows a liquid to flow and take the shape of its container, although it may not completely fill the container. A liquid's volume is constant: regardless of the size and shape of the container in which the liquid is held, the volume of the liquid remains the same. This is why measuring cups used in cooking, such as those pictured in **Figure 3-5**, can be made in a variety of shapes yet still measure the same volume. Because of the way the particles of a liquid are packed, liquids are virtually incompressible. Like solids, liquids tend to expand when heated.

Gases A **gas** is a form of matter that flows to conform to the shape of its container and fills the entire volume of its container. Examples of gases include neon, which is used in the lighted artwork in **Figure 3-6**; methane, which is used in cooking; and air, which is a mixture of gases. Compared to solids and liquids, the particles of gases are very far apart. Because of the significant amount of space between particles, gases are easily compressed. The **problem-solving LAB** in this section poses several important questions about the practical use of compressed gas.

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



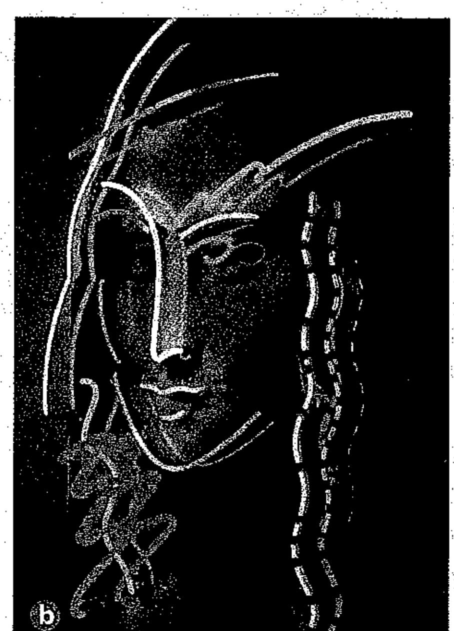


Figure 3-6

ⓐ Molecules in a gas are far apart and freely moving.
ⓑ Neon gas completely fills the tubes of the electric artwork.

Section 3.2 Changes in Matter

You learned in Section 3.1 that scientists can describe matter in terms of physical and chemical properties. For example, a physical property of copper allows it to be drawn into copper wire, and a chemical property of copper accounts for the fact that when a solution of copper ions is combined with ammonia, the copper solution changes to a deep blue color. The key concept in both of these examples is that the substance copper changed in some way. In this section, you'll explore how matter changes as a result of its physical and chemical properties.

Objectives

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

Vocabulary

physical change
chemical change
law of conservation of mass

Physical Changes

A substance often undergoes changes that result in a dramatically different appearance yet leave the composition of the substance unchanged. An example is the crumpling of a sheet of aluminum foil. While the foil goes from a smooth, flat, mirrorlike sheet to a round, compact ball, the actual composition of the foil is unchanged—it is still aluminum. Changes such as this, which alter a substance without changing its composition, are known as **physical changes**. Cutting a sheet of paper and breaking a crystal are other examples of physical changes in matter. Can you name some other physical changes? Your list might include verbs such as bend, grind, crumple, split, and crush, all of which indicate physical change.

As with other physical properties, the state of matter depends on the temperature and pressure of the surroundings. As temperature and pressure change, most substances undergo a change from one state (or phase) to another. For example, at atmospheric pressure and at temperatures below 0°C, water is in its solid state, which is known as ice. As heat is added to the ice, it melts and becomes liquid water. This change of state is a physical change because even though ice and water have very different appearances, their composition is the same. If the temperature of the water increases to 100°C, the water begins to boil and liquid water is converted to steam. Melting and formation of a gas are both physical changes and phase changes. **Figure 3-7** shows condensation, another common phase change. When you encounter terms such as boil, freeze, condense, vaporize, or melt in your study of chemistry, the meaning generally refers to a phase change in matter.

Try at Home LAB

See page 953 in Appendix E for
Comparing Frozen Liquids

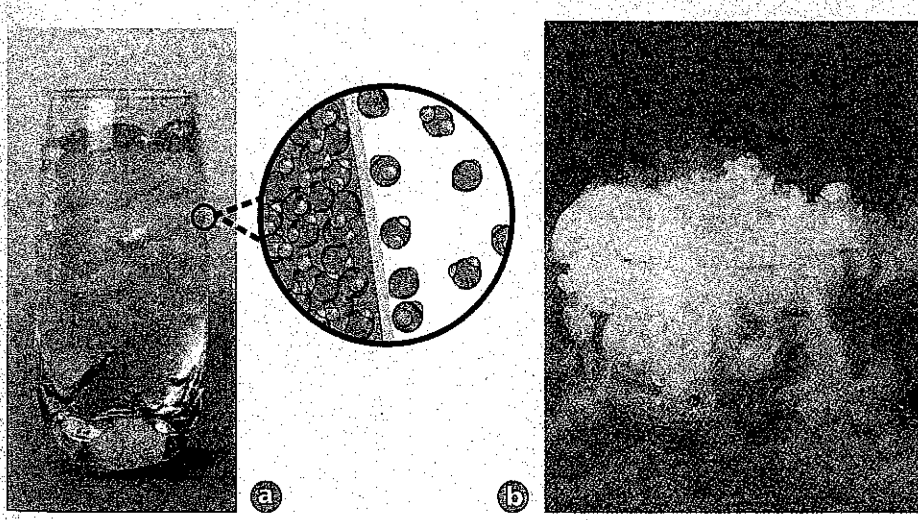


Figure 3-7

(a) Condensation on an icy beverage glass is the result of the phase change of water in a gaseous state to water in a liquid state.
(b) The characteristic "fog" of dry ice is actually fine water droplets formed by condensation of water vapor from the air surrounding the very cold dry ice. Refer to **Table C-1** in Appendix C for a key to atom color conventions.

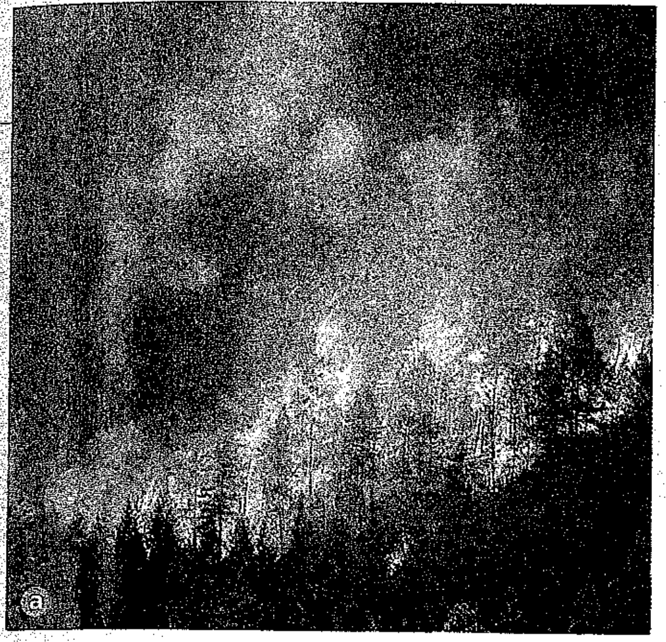


Figure 3-9

ⓐ Energy changes indicate chemical reactions. For example, the burning of wood is a common example of a reaction that releases heat.
ⓑ The change in the smell of a substance or the production of an odor may be an indication of a chemical reaction

Evidence of a chemical reaction As **Figure 3-8a** shows, rust is a brownish-orange powdery substance that looks very different from iron and oxygen. Rust is not attracted to a magnet, whereas iron is. The observation that the product (rust) has different properties than the reactants (iron and oxygen) is evidence that a chemical reaction has taken place. A chemical reaction always produces a change in properties. **Figures 3-8 and 3-9** illustrate several common indicators of chemical change. The **CHEMLAB** at the end of the chapter provides a practical laboratory experience with chemical reactions.

Name: ______________________________ Period: _________

Lesson 2 - Classification of Matter & Its Changes Quiz

After taking your notes answer the following questions and submit them next class.

1. Which of the following is/are a pure substance?
   a. element
   b. compound
   c. homogenous mixture
   d. heterogeneous mixture

2. Explain the difference between a homogeneous and heterogeneous mixture.

3. All of these are physical properties except (if you don't know what a term means look it up)
   a. rusting
   b. density
   c. melting point
   d. solubility

4. Which of these is an example of a physical change?
   a. baking a cake
   b. melting ice
   c. toasting a marshmallow
   d. digesting a hot dog

5. All of these are chemical properties except (if you don't know what a term means look it up)
   a. hardness
   b. flammability
   c. corrosiveness
   d. explosiveness

6. Which of these is an example of a chemical change?
   a. freezing biological samples for storage
   b. detonation of TNT
   c. evaporation of gasoline
   d. breaking a plate