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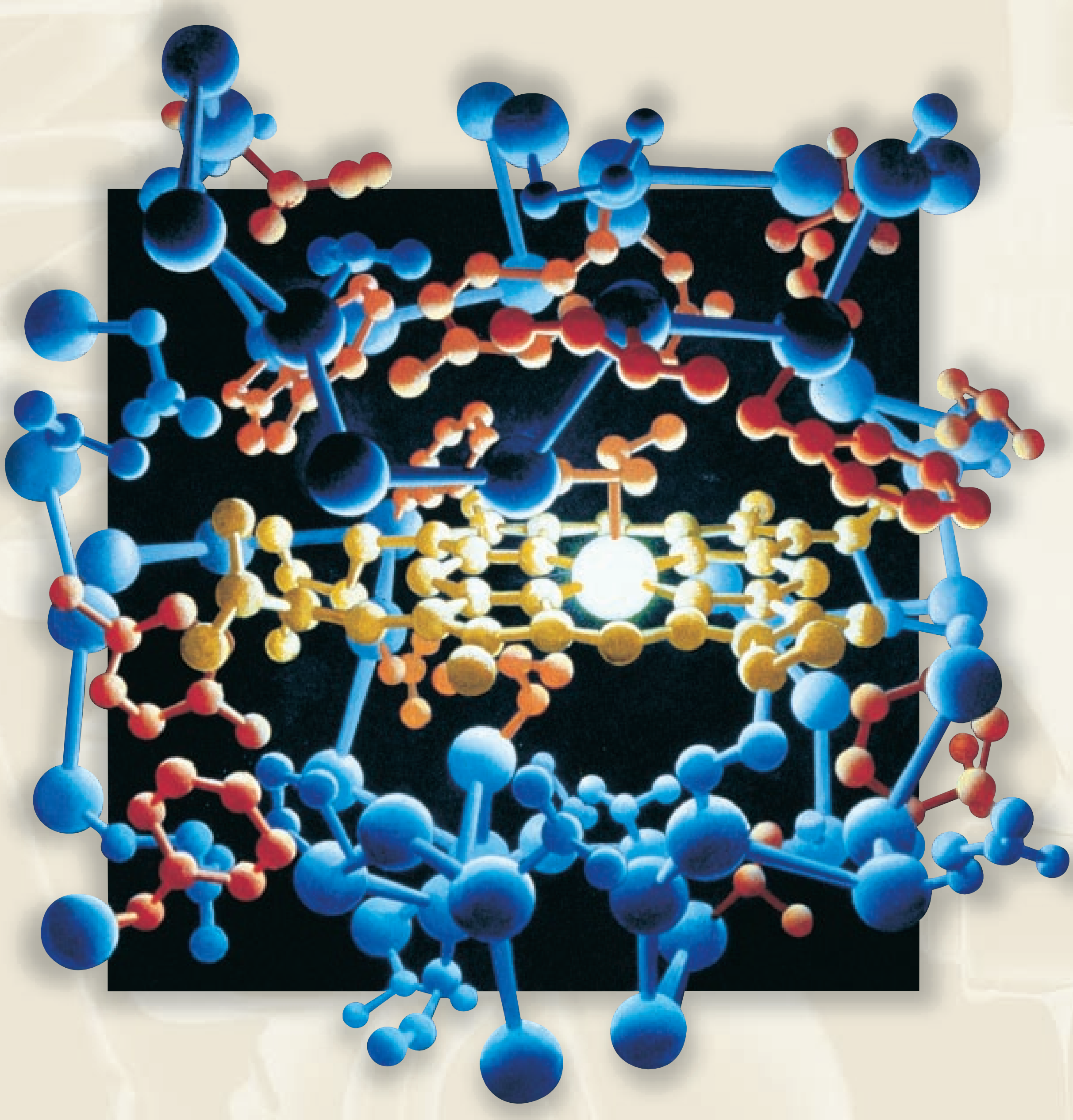
CHAPTER 1

Matter and Change



Chemistry is central to all of the sciences.

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Chemistry Is a Physical Science

SECTION 1-1

OBJECTIVES

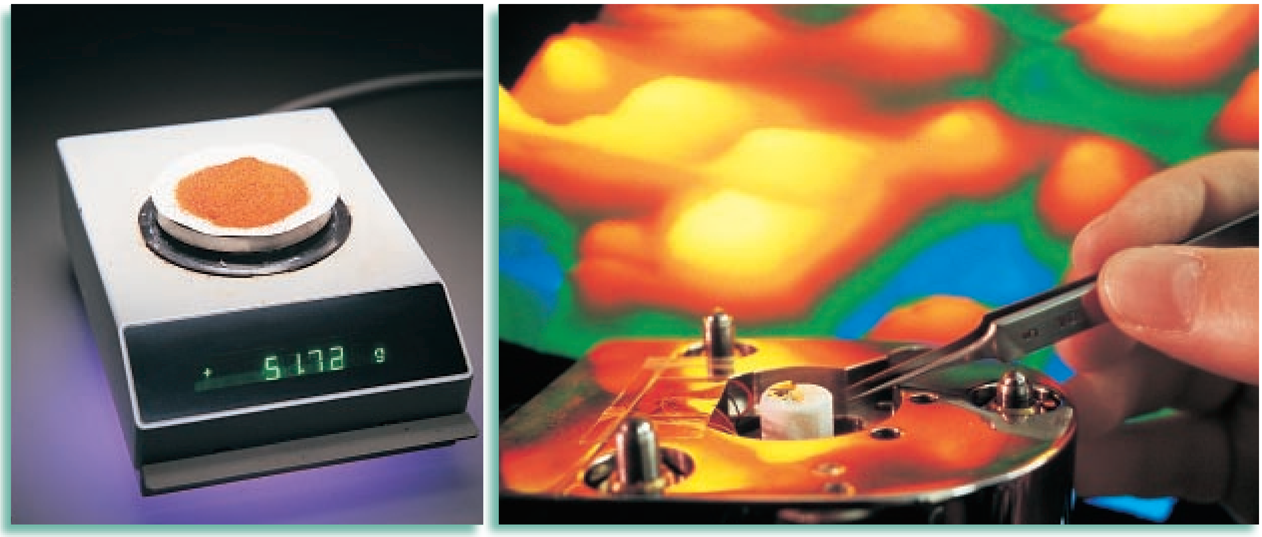
- Define *chemistry.*
- List examples of the branches of chemistry.
- Compare and contrast basic research, applied research, and technological development.

The natural sciences were once divided into two broad categories: the biological sciences and the physical sciences. Living things are the main focus of the biological sciences. The physical sciences focus mainly on nonliving things. However, because we now know that both living and nonliving matter have a chemical structure, chemistry is central to all the sciences, and there are no longer distinct divisions between the biological and physical sciences.

Chemistry *is the study of the composition, structure, and properties of matter and the changes it undergoes*. Chemistry deals with questions such as, What is that material made of? What is its makeup and internal arrangement? How does it behave and change when heated, cooled, or mixed with other materials and why does this behavior occur? Chemists answer these kinds of questions in their daily work.

Instruments are routinely used in chemistry to extend our ability to observe and make measurements. Instruments make it possible, for example, to look at microstructures—things too tiny to be seen with the unaided eye. The scanning electron microscope reveals tiny structures by beaming particles called electrons at materials. When the electrons hit a material, they scatter and produce a pattern that shows the material's microstructure. Invisible rays called X rays can also be used to

FIGURE 1-1 A balance (a) is an instrument used to measure the mass of materials. A sample of DNA placed in a scanning tunneling microscope produces an image (b) showing the contours of the DNA's surface.



(a) **(b)**

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"look at" microstructures. The patterns that appear, called X-ray diffraction patterns, can be analyzed to reveal the arrangement of atoms, molecules, or other particles that make up the material. By learning about microstructures, chemists can explain the behavior of macrostructures—the visible things all around you.

Branches of Chemistry

Chemistry includes many different branches of study and research. The following are six main areas, or branches, of study. But like the biological and physical sciences, these branches often overlap.

1. *Organic chemistry*—the study of most carbon-containing compounds
2. *Inorganic chemistry*—the study of all substances not classified as organic, mainly those compounds that do not contain carbon
3. *Physical chemistry*—the study of the properties and changes of matter and their relation to energy
4. *Analytical chemistry*—the identification of the components and composition of materials
5. *Biochemistry*—the study of substances and processes occurring in living things
6. *Theoretical chemistry*—the use of mathematics and computers to understand the principles behind observed chemical behavior and to design and predict the properties of new compounds

In all areas of chemistry, scientists work with chemicals. *A* **chemical** *is any substance that has a definite composition.* For example, consider the material called sucrose, or cane sugar. It has a definite composition in terms of the atoms that compose it. It is produced by certain plants in the chemical process of photosynthesis. Sucrose is a chemical. Carbon dioxide, water, and countless other substances are chemicals as well.

Knowing the properties of chemicals allows chemists to find suitable uses for them. For example, researchers have synthesized new substances, such as artificial sweeteners and synthetic fibers. The reactions used to make these chemicals are carried out on a large scale to make new products such as sweeteners and fabrics available for consumers.

Basic Research

Basic research is carried out for the sake of increasing knowledge, such as how and why a specific reaction occurs and what the properties of a substance are. Chance discoveries can be the result of basic research. The properties of Teflon, for example, were first discovered by accident. A researcher named Roy Plunkett was puzzled by the fact that a gas cylinder used for an experiment appeared to be empty even though the measured mass of the cylinder clearly indicated there was something inside. Plunkett cut the cylinder open and found a white solid. Through basic research, Plunkett's research team determined the nonstick properties, chemical structure, and chemical composition of the new material.

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Applied Research

Applied research is generally carried out to solve a problem. For example, when refrigerants escape into the upper atmosphere, they damage the ozone layer, which helps block harmful ultraviolet rays from reaching the surface of Earth. In response to concerns that this atmospheric damage could pose potential health problems, chemists have developed new refrigerants. In applied research, the researchers are driven not by simple curiosity or a desire to know but by a desire to solve a specific problem.

FIGURE 1-2 The chemical structure of the material in an optical fiber gives it the property of total internal reflection. This property, which allows these fibers to carry light, was discovered through basic and applied research. The use of this property to build telecommunications networks by sending data on light pulses is the technological development of fiber optics.

Technological Development

Technological development typically involves the production and use of products that improve our quality of life. Examples include computers, catalytic converters for cars, and biodegradable materials.

Technological applications often lag far behind the basic discoveries that are eventually used in the technologies. For example, nonstick cookware, a technological application, was developed well after the accidental discovery of Teflon. When it was later discovered that the Teflon coating on cookware often peeled off, a new problem had to be solved. Using applied research, scientists were then able to improve the bond between the Teflon and the metal surface of the cookware so that it did not peel.

Basic research, applied research, and technological development often overlap. Discoveries made in basic research may trigger ideas for applications that can result in new technologies. For example, knowledge of crystals and the behavior of light was gained from basic research, and this knowledge was used to develop lasers. It was then discovered that pulses of light from lasers can be sent through optical fibers. Today, information, such as telephone messages and cable television signals, can now be carried quickly over long distances using fiber optics.

SECTION REVIEW

1. Define *chemistry*.
2. Name the six branches of study in chemistry.
3. Compare and contrast basic research, applied research, and technological development.

Modern Alchemy

HISTORICAL PERSPECTIVE

Until a hundred years ago, chemists were still debating the validity of John Dalton's atomic theory. Few, however, challenged the notion that the elements were unchangeable. Near the beginning of the twentieth century, the discovery of some new elements and the strange radiation they emitted established the connection between atoms and the elements while resurrecting an ancient notion long discarded by science.

Before Chemistry

Until the chemical revolution of the seventeenth and eighteenth centuries, most theories about matter were based on the ideas of the ancient Greek philosopher Aristotle. He postulated that all matter consisted of four elements: earth, water, air, and fire. In turn, each of these elements exhibited two of four fundamental properties: moistness, dryness, coldness, and hotness. By altering these basic properties, Aristotle claimed, the elements could be transformed, or transmuted, into one another.

The interior of an alchemist's laboratory is depicted by artist Eugene Isabey.

The practical pursuit of transmutation became known as alchemy, and for more than 1,500 years investigators searched in vain for alchemical methods that would transform common metals such as mercury and lead into precious gold. Then, in the seventeenth century, chemists began to question Aristotle's assumptions. They defined an element as a material that can't be broken down into simpler substances, and with no evidence to support the possibility of transmutation of the modern elements, alchemy fell into ill repute.

Strange Rays

In 1896, French scientist Henri Becquerel discovered that the element uranium gave off a strange, invisible radiation. The report of these "uranic rays" caught the attention of a young chemist by the name of Marie Curie.

Working with her husband, Pierre, Marie began to test various substances for radioactivity. Analyzing a mineral composite called pitchblende, a known source of uranium, she was startled to find that the composite's level of radioactivity was greater than that of a similar amount of pure uranium. This meant that another radioactive material besides uranium was present in the pitchblende.

After months of tedious work, Marie had isolated two new radioactive elements, which she

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named polonium and radium, from pitchblende. Curie later won the Nobel Prize for her discovery, but at the time, she was troubled by the seemingly constant energy source of the radioactive process that had led her to the new elements. As she wrote in 1900:

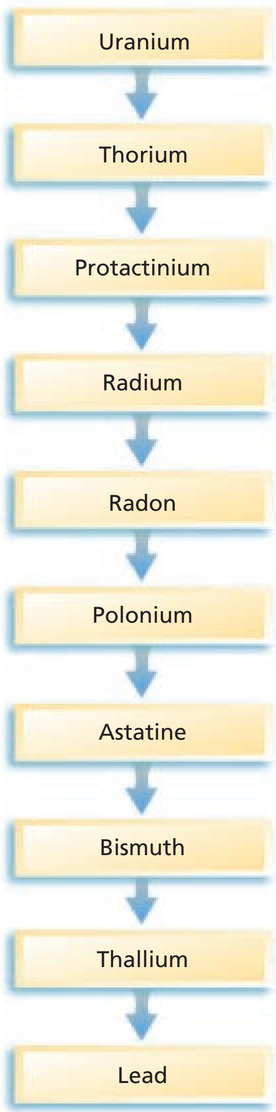
> *The emission of the uranic rays is very constant . . . The uranium shows no appreciable change of state, no visible chemical transformation, it remains, in appearance at least, the same as ever, the source of the energy it discharges remains undetectable. . . .*

The Revival of Transmutation

While Marie Curie was making her momentous discoveries, other scientists were establishing that the chemical elements were actually different types of atoms. The connection between this emerging theory of matter and radioactivity was made by the famous scientist Ernest Rutherford.

In 1902, Rutherford and his assistant, Frederick Soddy, reported that the radioactivity of a sealed sample of thorium (a known element determined to be radioactive by the Curies) had actually *increased* over time. This increase was accompanied by the simultaneous evolution of a radioactive gas. The two investigators began to question whether radioactive elements were as stable as elements were supposed to be. After further studies, Rutherford and Soddy presented their shocking explanation:

> *The cause and nature of radioactivity is at once an atomic phenomenon and the accompaniment of a chemical change in which new kinds of matter are produced. The two considerations force us to the conclusion that radioactivity is a manifestation of subatomic chemical change.*



A simplified decay diagram for uranium

Rutherford and Soddy's "subatomic chemical change" was nothing less than transmutation. Nature had turned out to be an alchemist!

The New Alchemy Explained

Rutherford later showed that the spontaneous transmutation, or decay, of radioactive atoms involves the emission of nuclear particles or high-energy waves known as gamma rays, or both. The atom's nucleus is consequently reconfigured, changing the atom into that of another element.

Thus, the source of energy in Marie Curie's uranium sample came from within the radioactive atoms. And although it seemed as if the energy output was constant, the sources of the radiation were continually changing as one radioactive element decayed into another.

Years later, it would be shown that the transmutation of certain elements could be deliberately initiated by bombarding nuclei with accelerated subatomic particles. But the goal of modern alchemy is no longer gold, as Soddy remarked in 1917:

> *If man ever achieves this control over Nature, it is quite certain that the last thing he would want to do would be to turn lead or mercury into gold*—for the sake of gold. *The energy that would be liberated, if the control of these sub-atomic processes were possible . . . would far exceed in importance and value the gold.*

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SECTION 1-2

Matter and Its Properties

OBJECTIVES

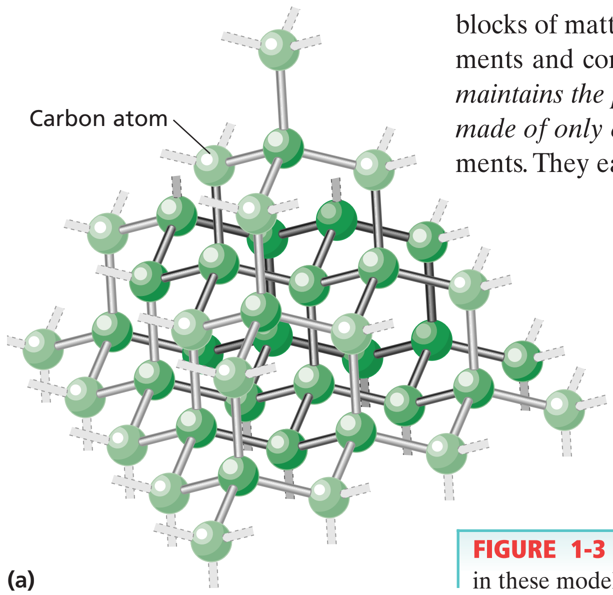
- Distinguish between the physical properties and chemical properties of matter.
- Classify changes of matter as physical or chemical.
- Explain the gas, liquid, and solid states in terms of particles.
- Distinguish between a mixture and a pure substance.

Look around you. You can see a variety of objects—books, desks, chairs, and perhaps trees or buildings outside. All those things are made up of matter, but exactly what is matter? What characteristics, or properties, make matter what it is? In this section, you will learn the answers to these questions.

Explaining what matter is involves finding properties that all matter has in common. That may seem difficult, given that matter takes so many different forms. For the moment, just consider one example of matter—a rock. The first thing you might notice is that the rock takes up space. In other words, it has *volume*. Volume is the amount of three-dimensional space an object occupies. All matter has volume. All matter also has a property called mass. **Mass** *is a measure of the amount of matter*. Mass is the measurement you make using a balance. **Matter** can thus be defined as *anything that has mass and takes up space*. These two properties are the general properties of all matter.

Basic Building Blocks of Matter

You know that matter comes in many forms. The fundamental building blocks of matter are atoms and molecules. These particles make up elements and compounds. *An* **atom** *is the smallest unit of an element that maintains the properties of that element. An* **element** *is a pure substance made of only one kind of atom.* Carbon, hydrogen, and oxygen are elements. They each contain only one kind of atom.



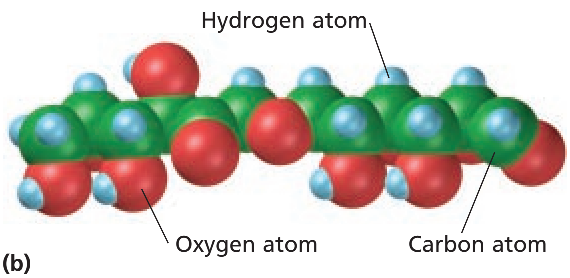


FIGURE 1-3 Both elements and compounds are made of atoms, as shown in these models of (a) diamond and (b) sucrose (table sugar).

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A **compound** *is a substance that is made from the atoms of two or more elements that are chemically bonded.* Many compounds consist of molecules. Water is an example of a compound. It is made of two elements, hydrogen and oxygen. The atoms of hydrogen and oxygen are chemically bonded to form a water molecule. You will learn more about the particles that make up compounds when you study chemical bonding in Chapter 6. For now, you can think of a *molecule* as the smallest unit of an element or compound that retains all of the properties of that element or compound.

Properties and Changes in Matter

Every substance, whether it is an element or a compound, has characteristic properties. Chemists use properties to distinguish between substances and to separate them. Most chemical investigations are related to or depend on the properties of substances.

A property may be a characteristic that defines an entire group of substances. That property can be used to classify an unknown substance as a member of that group. For example, one large group of elements is the metals. The distinguishing property of metals is that they conduct electricity well. Therefore, if an unknown element is tested and found to conduct electricity well, it is a metal.

Properties can help reveal the identity of an unknown substance. However, conclusive identification usually cannot be made based on only one property. Comparisons of several properties can be used together to establish the identity of an unknown. Properties are either intensive or extensive. **Extensive properties** *depend on the amount of matter that is present*. Such properties include volume, mass, and the amount of energy in a substance. In contrast, **intensive properties** *do not depend on the amount of matter present*. Such properties include the melting point, boiling point, density, and ability to conduct electricity and heat. These properties are the same for a given substance regardless of how much of the substance is present. Properties can also be grouped into two general types: physical properties and chemical properties.

Physical Properties and Physical Changes

A **physical property** *is a characteristic that can be observed or measured without changing the identity of the substance.* Physical properties describe the substance itself, rather than describing how it can change into other substances. Examples of physical properties are melting point and boiling point. Those points are, respectively, the temperature at which a substance melts from solid to liquid and the temperature at which it boils from liquid to gas. For example, water melts from ice to liquid at 0°C (273 K or 32°F). Liquid water boils to vapor at 100°C (373 K or 212°F).

FIGURE 1-4 Because it possesses certain chemical properties, a test strip containing Benedict's solution is used to test for the presence of sugar in urine. The test strip is dipped into the sample. The test strip is then matched to a color scale to determine the sugar level in the urine.

A change in a substance that does not involve a change in the identity of the substance is called a **physical change.** Examples of physical changes include grinding, cutting, melting, and boiling a material. These types of changes do not change the identity of the substance present.

Melting and boiling are part of an important class of physical changes called changes of state. As the name suggests, *a* **change of state** *is a physical change of a substance from one state to another*. The three common states of matter are solid, liquid, and gas.

Matter in the **solid** *state has definite volume and definite shape.* For example, a piece of quartz or coal keeps its size and its shape, regardless of the container it is in. Solids have this characteristic because the particles in them are packed together in relatively fixed positions. The particles are held close together by strong attractive forces between them, and only vibrate about fixed points.

Matter in the **liquid** *state has a definite volume but an indefinite shape;* a liquid assumes the shape of its container. For example, a given quantity of liquid water takes up a definite amount of space, but the water takes the shape of its container. Liquids have this characteristic because the particles in them are close together but can move past one another. The particles in a liquid move more rapidly than those in a solid. This causes them to overcome temporarily the attractive forces between them, allowing the liquid to flow.

Matter in the **gas** *state has neither definite volume nor definite shape.* For example, a given quantity of helium expands to fill any size container and takes the shape of the container. All gases have this characteristic because they are composed of particles that move very rapidly and are at great distances from one another compared with the particles of liquids and solids.

At these great distances, the attractive forces between gas particles are much weaker than those in liquids and solids.

An important fourth state of matter is **plasma.** Plasma is a *high-temperature physical state of matter in which atoms lose their electrons* (which you may know about from your earlier work in general science). Plasma is found in a fluorescent bulb.

Melting, the change from solid to liquid, is an example of a change of state. Boiling is a change of state from liquid to gas. Freezing, the opposite of melting, is the change from a liquid to a solid. A change of state does not affect the identity of the substance. For example, when ice melts to liquid water or when liquid water boils to form water vapor, the same substance, water, is still present, as shown in Figure 1-6. The water has simply changed state, but it has not turned into a different compound. Only the distances and interactions between the particles that make up water have changed.

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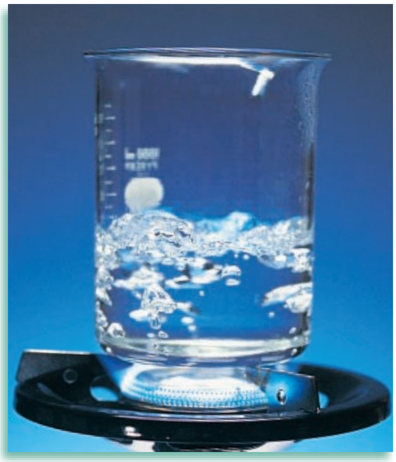

FIGURE 1-5 Water boils at 100°C no matter how much water is in the container. Boiling point is an intensive property.

Chemical Properties and Chemical Changes

Physical properties can be observed without changing the identity of the substance, but properties of the second type—chemical properties—cannot. *A* **chemical property** *relates to a substance's ability to undergo changes that transform it into different substances.* Chemical properties are easiest to see when substances react to form new substances.

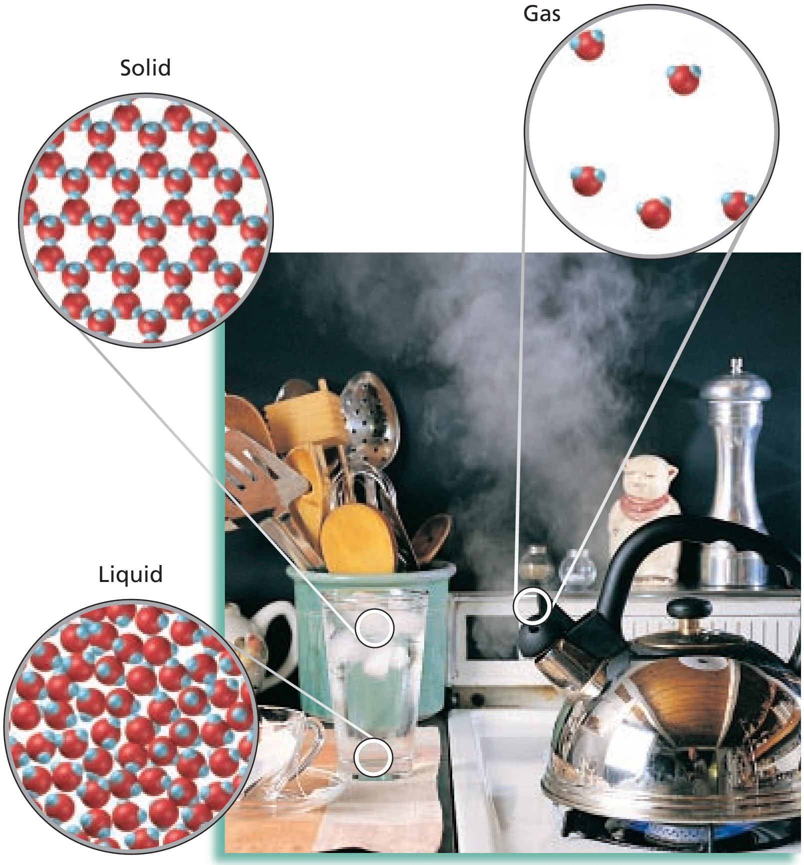

FIGURE 1-6 Models for water in three states. The molecules are close together in the solid and liquid states but far apart in the gas state. The molecules in the solid state are relatively fixed in position, but those in the liquid and gas states can flow around each other.

For example, the ability of charcoal (carbon) to burn in air is a chemical property. When charcoal burns, it combines with oxygen in air to become a new substance, carbon dioxide gas. After the chemical change, the original substances, carbon and oxygen, are no longer present. A different substance with different properties has been formed. Other examples of chemical properties include the ability of iron to rust by combining with oxygen in air and the ability of silver to tarnish by combining with sulfur.

A change in which one or more substances are converted into different substances is called a **chemical change** *or* **chemical reaction.** *The substances that react in a chemical change are called the* **reactants.** *The substances that are formed by the chemical change are called the* **products.** In the case of burning charcoal, carbon and oxygen are the reactants in a combustion, or burning, reaction. Carbon dioxide is the product. The chemical change can be described as follows:

Carbon plus oxygen yields (or forms) carbon dioxide.

Arrows and plus signs can be substituted for the words *yields* and *plus,* respectively:

$$\text{carbon} + \text{oxygen} \longrightarrow \text{carbon dioxide}$$

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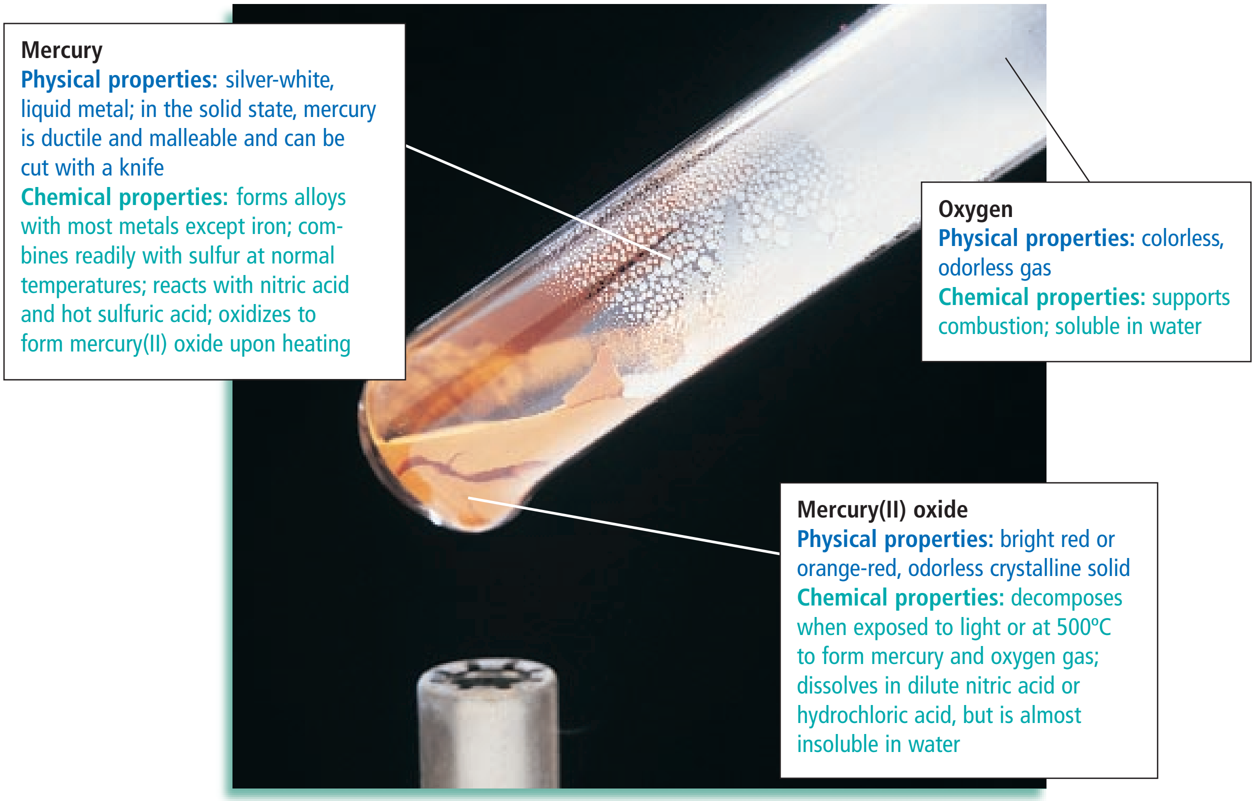

FIGURE 1-7 When mercury(II) oxide is heated, it decomposes to form oxygen gas and mercury (which can be seen on the side of the test tube). Decomposition is a chemical change that can be observed by comparing the properties of mercury(II) oxide, mercury, and oxygen.

The decomposition of the mercury compound shown in Figure 1-7 can be expressed as follows:

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

Chemical changes and reactions, such as combustion and decomposition, form products whose properties differ greatly from those of the reactants. However, chemical changes do not affect the total amount of matter present before and after a reaction. The amount of matter, and therefore the total mass, remains the same.

Energy and Changes in Matter

When physical or chemical changes occur, energy is always involved. The energy can take several different forms, such as heat or light. Sometimes heat provides enough energy to cause a physical change, as in the melting of ice, and sometimes heat provides enough energy to cause a chemical change, as in the decomposition of water vapor to form oxygen gas and hydrogen gas. But the boundary between physical and chemical changes isn't always so clear. For example, while most chemists would consider the dissolving of sucrose in water to be a physical change, many chemists would consider the dissolving of table salt in water to be a chemical change. As you learn more about the structure of matter, you will better understand why the boundaries between chemical and physical changes can be confusing.

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Although energy can be absorbed or released in a change, it is not destroyed or created. It simply assumes a different form. This is the law of conservation of energy. Accounting for all the energy present before and after a change is not a simple process. But scientists who have done such experimentation are confident that the total amount of energy remains the same.

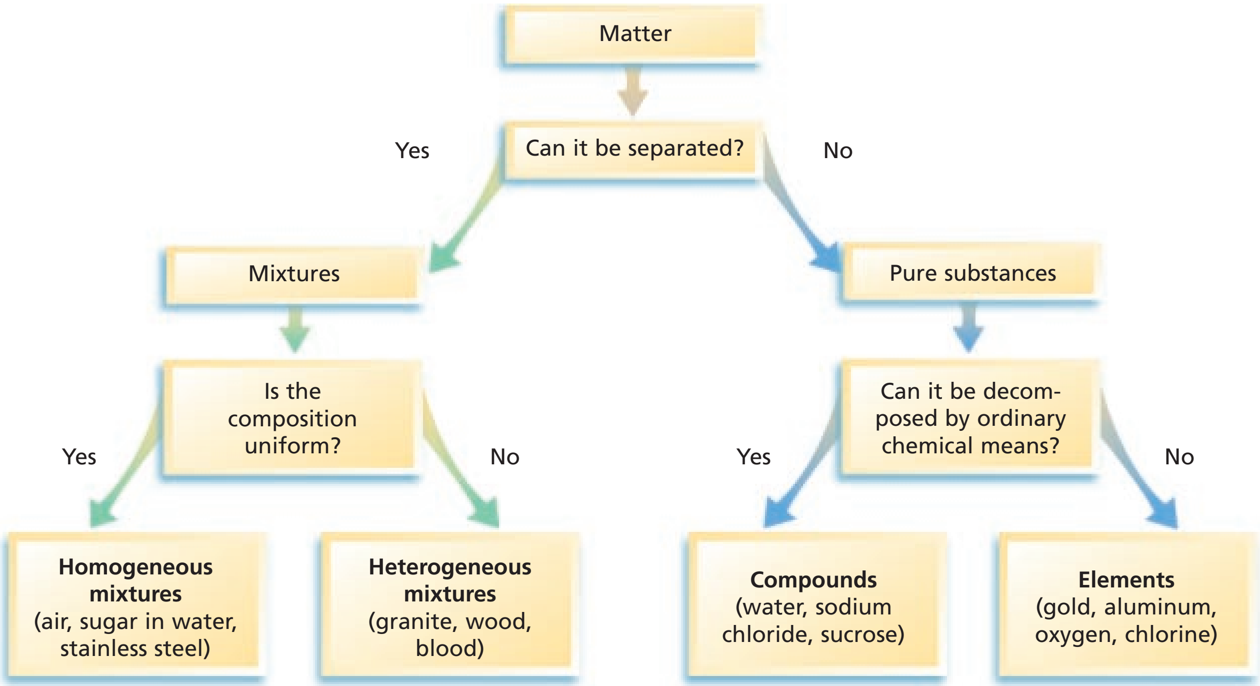
Classification of Matter

The variety of forms in which matter exists is enormous. However, all matter can be classified into one of two groups: pure substances or mixtures. A pure substance can be an element or compound. The composition of a pure substance is the same throughout and does not vary from sample to sample. Mixtures, in contrast, contain more than one substance. They can vary in composition and properties from sample to sample and sometimes from one part of a sample to another part of the same sample. All matter, whether it is a pure substance or a mixture, can be classified in terms of uniformity of composition and properties of a given sample. Figure 1-8 illustrates the overall classification of matter into elements, compounds, and mixtures.

Mixtures

You deal with mixtures every day. Nearly every object around you, including most things you eat and drink and even the air you breathe, is a mixture. *A* **mixture** *is a blend of two or more kinds of matter, each*

FIGURE 1-8 This classification scheme for matter shows the relationships among mixtures, compounds, and elements.



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(a) (b) (c)

FIGURE 1-9 (a) Barium chromate can be separated from the solution in the beaker using filtration. (b) A centrifuge can be used to separate certain solid components. The centrifuge spins rapidly, which causes the solids to settle to the bottom of the test tube. (c) The components of an ink can be separated using paper chromatography.

of which retains its own identity and properties. The parts, or components, of a mixture are simply mixed together physically and can usually be separated. As a result, the properties of a mixture are a combination of the properties of its components. Because mixtures can contain various amounts of different substances, a mixture's composition must be specified. This is often done in terms of percentage by mass or by volume. For example, a mixture might be 5% sodium chloride and 95% water by mass.

Some mixtures are *uniform in composition;* that is, they are said to be **homogeneous.** They have the same proportion of components throughout. *Homogeneous mixtures are also called* **solutions.** A salt-water solution is an example of such a mixture. Other mixtures are *not uniform throughout;* that is, they are **heterogeneous.** For example, in a mixture of clay and water, heavier clay particles concentrate near the bottom of the container.

Some mixtures can be separated by filtration or vaporized to separate the different components. Filtration can be used to separate a mixture of solid barium chromate from the other substances, as shown in the beaker in Figure 1-9(a). The yellow barium compound is trapped by the filter paper, but the solution passes through. If the solid in a liquid-solid mixture settles to the bottom of the container, the liquid can be carefully poured off (decanted). A centrifuge (Figure 1-9(b)) can be used to separate some solid-liquid mixtures, such as those in blood. Another technique, called paper chromatography, can be used to separate mixtures of dyes or pigments because the different substances will move at different rates on the paper (Figure 1-9(c)).

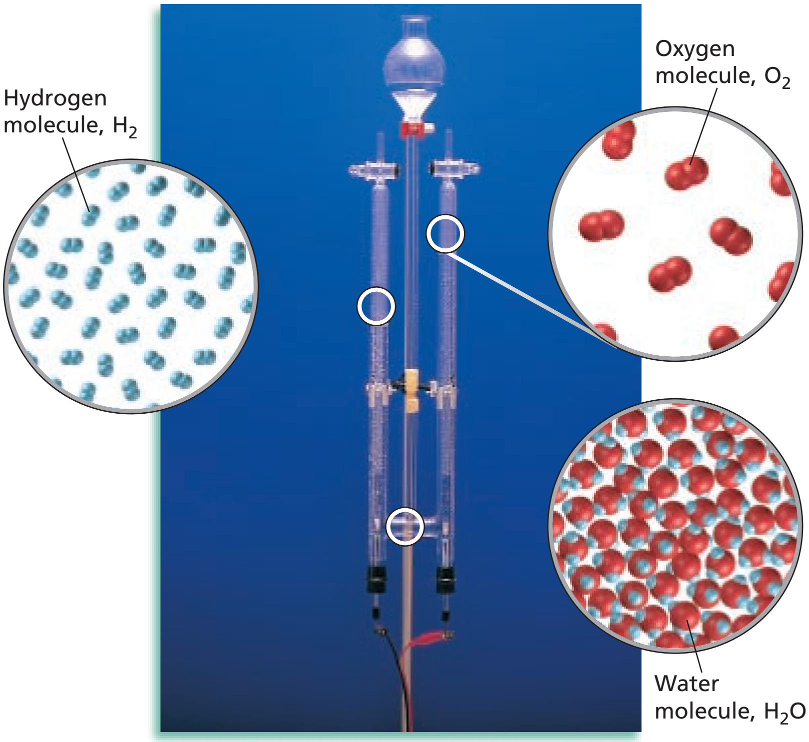
Pure Substances

In contrast to a mixture, a pure substance is homogenous as a single entity. *A* **pure substance** *has a fixed composition and differs from a mixture in the following ways:*

1. *Every sample of a given pure substance has exactly the same characteristic properties.* All samples of a pure substance have the same characteristic physical and chemical properties. These properties are so specific that they can be used to identify the substance. In contrast, the properties of a mixture depend on the relative amounts of the mixture's components.
2. *Every sample of a given pure substance has exactly the same composition.* Unlike mixtures, all samples of a pure substance have the same makeup. For example, pure water is always 11.2% hydrogen and 88.8% oxygen by mass.

Pure substances are either compounds or elements. A compound can be decomposed, or broken down, into two or more simpler compounds or elements by a chemical change. Water is a compound made of hydrogen and oxygen chemically bonded to form a single substance. Water can be broken down into hydrogen and oxygen through a chemical reaction called electrolysis, as shown in Figure 1-10(a).

Sucrose is made of carbon, hydrogen, and oxygen. Sucrose breaks down to form the other substances shown in Figure 1-10(b). Under intense heating, sucrose breaks down to produce carbon and water.



(a)

(b)

FIGURE 1-10 (a) Passing an electric current through water causes the compound to break down into the elements hydrogen and oxygen, which differ in composition from water. (b) When sucrose is heated, it caramelizes. When it is heated to a high temperature, it breaks down completely into carbon and water.

FIGURE 1-11 The labeling on a reagent bottle lists the grade of the reagent and the percentages of impurities for that grade. What grade is this chemical?

TABLE 1-1 Some Grades of Chemical Purity

Increasing purity (↑)
Primary standard reagents
ACS (American Chemical Society–specified reagents)
USP (United States Pharmacopoeia standards)
CP (chemically pure; purer than technical grade)
NF (National Formulary specifications)
FCC (Food Chemical Code specifications)
Technical (industrial chemicals)

Laboratory Chemicals and Purity

The chemicals in laboratories are generally treated as if they are pure. However, all chemicals have some impurities. Chemical grades of purity are listed in Table 1-1. The purity ranking of the grades can vary when agencies differ in their standards. For some chemicals, the USP grade may specify higher purity than the CP grade. For other chemicals, the opposite may be true. However, the primary standard reagent grade is always purer than the technical grade for the same chemical. Chemists need to be aware of the kinds of impurities in a reagent because these impurities could affect the results of a reaction. For example, the chemical label shown in Figure 1-11 shows the impurities for that grade. The chemical manufacturer must ensure that the standards set for that reagent by the American Chemical Society are met.

SECTION REVIEW

1. a. What is the main difference between physical properties and chemical properties?
   b. Give an example of each.
2. Classify each of the following as either a physical change or a chemical change.
   a. tearing a sheet of paper
   b. melting a piece of wax
   c. burning a log
3. You are given a sample of matter to examine. How do you decide whether the sample is a solid, liquid, or gas?
4. Contrast mixtures with pure substances.

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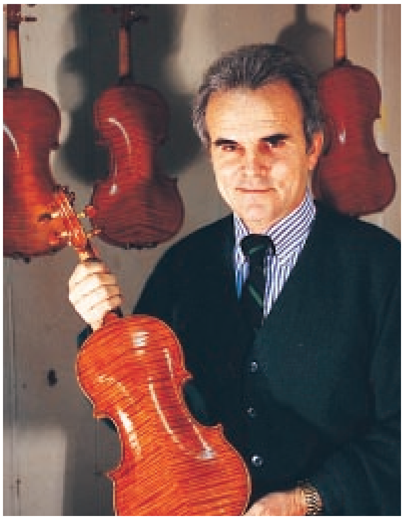
Secrets of the Cremona Violins

What are the most beautiful sounding of all violins? Most professionals will pick the instruments created in Cremona, Italy, following the Renaissance. At that time, Antonio Stradivari, the Guarneri family, and other designers created instruments of extraordinary sound that have yet to be matched. The craftsmen were notoriously secretive about their techniques, but, based on 20 years of research, Dr. Joseph Nagyvary, a professor of biochemistry at Texas A&M University, thinks he has discovered the key to the violins' sound hidden in the chemistry of their materials.



Dr. Nagyvary and his violin

According to Dr. Nagyvary, Stradivarius instruments are nearly free of the shrill, high-pitched noises produced by modern violins. Generally, violin makers attribute this to the design of the instrument, but Dr. Nagyvary traces it to a different source. In Stradivari's day, wood for the violins was transported by floating it down a river from the mountains to Venice, where it was stored in sea water. Dr. Nagyvary first theorized that the soaking process could have removed ingredients from the wood that made it inherently noisy. His experiments revealed that microbes and minerals also permeated the wood, making their own contribution to the mellow musical sound.

Dr. Nagyvary found other clues to the sound of the violins in the work of Renaissance alchemists. Aside from trying to turn lead into gold, alchemists made many useful experiments, including investigating different chemical means of preserving wood in musical instruments. Attempting to duplicate their techniques and to reproduce the effects of sea water, Dr. Nagyvary soaks all his wood in a "secret" solution. One of his favorite ingredients is a cherry-and-plum puree, which contains an enzyme called pectinase. The pectinase softens the wood, making it resonate more freely.

"The other key factor in a violin's sound," says Dr. Nagyvary, "is the finish, which is the filler and the varnish covering the instrument. Most modern finishes are made from rubbery materials, which limit the vibrations of the wood." Modern analysis has revealed that the Cremona finish was different: it was a brittle mineral microcomposite of a very sophisticated nature. According to historical accounts, all violin makers, including Stradivari, procured their varnishes from the local drugstore chemist, and they didn't even know what they were using! Dr. Nagyvary thinks this unknown and unsung drugstore chemist could have been the major factor behind the masterpieces for which violin makers like Stradivari received exclusive credit. By now, Dr. Nagyvary and his co-workers have identified most of the key ingredients of the Cremona finish.

Many new violins made from the treated wood and replicated finish have been made, and their sound has been analyzed by modern signal analyzers. These violins have been favorably compared with authentic Stradivari violins.

A number of expert violinists have praised the sound of Dr. Nagyvary's instruments, but some violin makers remain skeptical of the chemist's claims. They insist that it takes many years to reveal just how good a violin is. In the meantime, most everyone agrees that the art and science of violin making are still epitomized by the instruments of Cremona.

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SECTION 1-3

Elements

Objectives

- Use a periodic table to name elements, given their symbols.
- Use a periodic table to write the symbols of elements, given their names.
- Describe the arrangement of the periodic table.
- List the characteristics that distinguish metals, nonmetals, and metalloids.

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As you have read, elements are pure substances that cannot be decomposed by chemical changes. The elements serve as the building blocks of matter. Each element has characteristic properties. The elements are organized into groups based on similar chemical properties. This organization of elements is the *periodic table,* which is shown in Figure 1-12 on the next page.

Introduction to the Periodic Table

Each small square of the periodic table shows the name of one element and the letter symbol for the element. For example, the first square, at the upper left, represents element 1, hydrogen, which has the atomic symbol H.

As you look through the table, you will see many familiar elements, including iron, sodium, neon, silver, copper, aluminum, sulfur, and lead. You can often relate the symbols to the English names of the elements. Though some symbols are derived from the element's older name, which was often in Latin, wolfram comes from the German name for tungsten. Table 1-2 lists some of those elements.

TABLE 1-2 ***Elements with Symbols Based on Older Names***

Modern name	Symbol	Older name
Antimony	Sb	stibium
Copper	Cu	cuprum
Gold	Au	aurum
Iron	Fe	ferrum
Lead	Pb	plumbum
Mercury	Hg	hydrargyrum
Potassium	K	kalium
Silver	Ag	argentum
Sodium	Na	natrium
Tin	Sn	stannum
Tungsten	W	wolfram

Periodic Table

Metals
Metalloids
Nonmetals

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub	113	114 Uuq	115	116 Uuh	117	118 Uuo
				58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
				90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

FIGURE 1-12 The periodic table of elements. The names of the elements can be found on Table A-6 in the appendix, pages 896–897.

The vertical columns of the periodic table are called **groups,** or **families.** Notice that they are numbered from 1 to 18 from left to right. Each group contains elements with similar chemical properties. For example, the elements in Group 2 are beryllium, magnesium, calcium, strontium, barium, and radium. All of these elements are reactive metals with similar abilities to bond to other kinds of atoms. The two major categories of elements are metals and nonmetals. Metalloids have properties intermediate between those of metals and nonmetals.

The horizontal rows of elements in the periodic table are called **periods.** Physical and chemical properties change somewhat regularly across a period. Elements that are close to each other in the same period tend to be more similar than elements that are farther apart. For example, in Period 2, the elements lithium and beryllium, in Groups 1 and 2, respectively, are somewhat similar in properties. However, their properties are very different from the properties of fluorine, the Period-2 element in Group 17.

The two sets of elements placed below the periodic table make up what are called the lanthanide series and the actinide series. These metallic elements fit into the table just after elements 57 and 89. They are placed below the table to keep the table from being too wide.

There is a section in the back of this book called the *Elements Handbook,* pages 726–783, which covers some representative elements in greater detail. You will use information from the handbook to complete the questions in the Handbook Search sections in the chapter reviews.

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Types of Elements

The periodic table is broadly divided into two main sections: metals and nonmetals. As you can see in Figure 1-12, the metals are at the left and in the center of the table. The nonmetals are toward the right. The elements along the dividing line show characteristics of both metals and nonmetals.

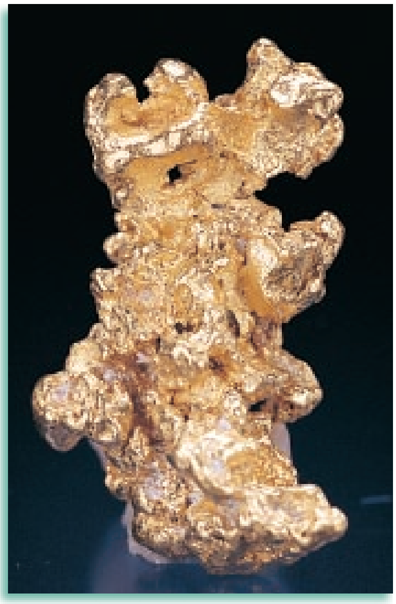
Metals

Some of the properties of metals may be familiar to you. For example, you can recognize metals by their shininess, or metallic luster. Perhaps the most important characteristic property of metals is the ease with which they conduct heat and electricity. Thus, *a* **metal** *is an element that is a good conductor of heat and electricity*.

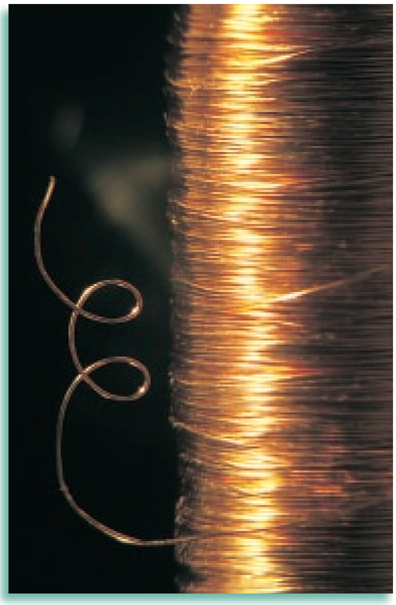
At room temperature, most metals are solids. Most metals also have the property of *malleability,* that is, they can be hammered or rolled into thin sheets. Metals also tend to be *ductile,* which means that they can be drawn into a fine wire. Metals behave this way because they have high *tensile strength,* the ability to resist breaking when pulled.

Although all metals conduct electricity well, metals also have very diverse properties. Mercury is a liquid at room temperature, whereas tungsten has the highest melting point of any element. The metals in Group 1 are so soft that they can be cut with a knife, yet others, like chromium, are very hard. Some metals, such as manganese and bismuth, are very brittle, yet others, such as iron and copper, are very malleable and ductile. Most metals have a silvery or grayish white *luster*. Two exceptions are gold and copper, which are yellow and reddish brown, respectively. Figure 1-13 shows examples of metals.

FIGURE 1-13 (a) Gold has a low reactivity, which is why it may be found in nature in relatively pure form. (b) Copper is used in wiring because it is ductile and is an excellent conductor of electricity. (c) Aluminum is malleable. It can be rolled into foil that is used for wrapping food.



(a)



(b)

(c)

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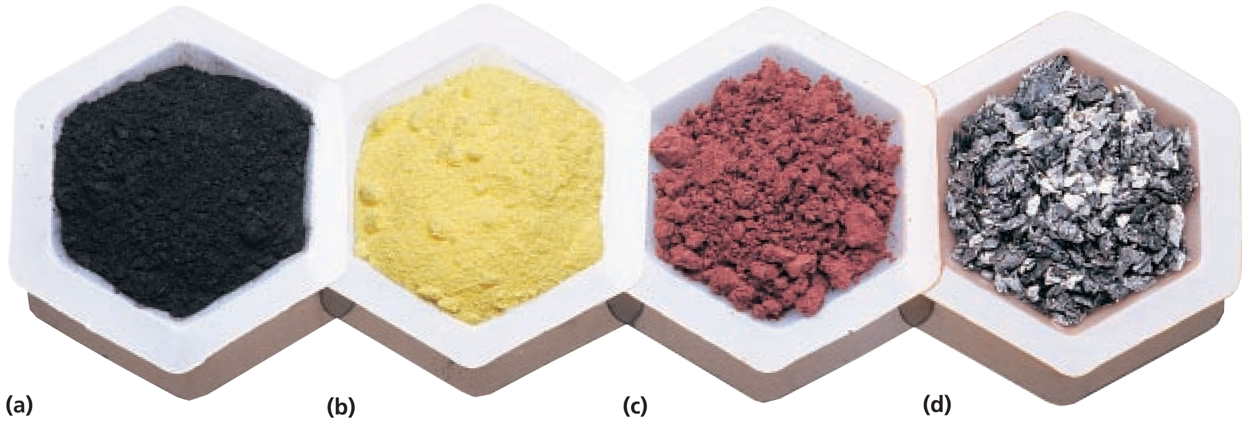

FIGURE 1-14 Various nonmetallic elements: (a) carbon, (b) sulfur, (c) phosphorus, and (d) iodine

Copper: A Representative Metal

Copper has a characteristic reddish color and a metallic luster. It is found naturally in minerals such as chalcopyrite and malachite. Pure copper melts at 1083°C and boils at 2567°C. It can be readily drawn into fine wire, pressed into thin sheets, and formed into tubing. Copper conducts electricity with little loss of energy.

Copper remains unchanged in pure, dry air at room temperature. When heated, it reacts with oxygen in air. It also reacts with sulfur and the elements in Group 17 of the periodic table. The green coating on a piece of weathered copper comes from the reaction of copper with oxygen, carbon dioxide, and sulfur compounds. Copper is an essential mineral in the human diet.

Nonmetals

Many nonmetals are gases at room temperature. These include nitrogen, oxygen, fluorine, and chlorine. One nonmetal, bromine, is a liquid. The solid nonmetals include carbon, phosphorus, selenium, sulfur, and iodine. These solids tend to be brittle rather than malleable and ductile. Some nonmetals are illustrated in Figure 1-14.

Low conductivity can be used to define nonmetals. *A* **nonmetal** *is an element that is a poor conductor of heat and electricity.* If you look at Figure 1-12, you will see that there are fewer nonmetals than metals.

Phosphorus: A Representative Nonmetal

Phosphorus is one of five solid nonmetals. Pure phosphorus is known in two common forms. Red phosphorus is a dark red powder that melts at 597°C. White phosphorus is a waxy solid that melts at 44°C. Because it ignites in air, white phosphorus is stored underwater.

Phosphorus is too reactive to exist in pure form in nature. It is present in huge quantities in phosphate rock, where it is combined with oxygen and calcium. All living things contain phosphorus.

FIGURE 1-15 Selenium is a nonmetal, though it looks metallic.

Metalloids

A stair-step line separates the metals from the nonmetals on the periodic table. Several of the elements in the vicinity of this line are often

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FIGURE 1-16 The noble gases helium, neon, argon, krypton, and xenon are all used to make lighted signs of various colors.

referred to as metalloids. *A* **metalloid** *is an element that has some characteristics of metals and some characteristics of nonmetals.* All metalloids are solids at room temperature. They tend to be less malleable than metals but not as brittle as nonmetals. Some metalloids, such as antimony, have a somewhat metallic luster.

Metalloids tend to be semiconductors of electricity. That is, their ability to conduct electricity is intermediate between that of metals and that of nonmetals. Metalloids are used in the semiconducting materials found in desktop computers, hand-held calculators, digital watches, televisions, and radios.

Noble Gases

The elements in Group 18 of the periodic table are the noble gases. These elements are generally unreactive. In fact, prior to 1962 no noble gas compounds had been identified. That year, the first noble gas compound, xenon tetrafluoride, was prepared. Their low reactivity sets noble gases apart from the other families of elements. Group-18 elements are gases at room temperature. Neon, argon, krypton, and xenon are all used in lighting. Helium is used in party balloons and weather balloons because it is less dense than air.

SECTION REVIEW

1. Use the periodic table on the inside back cover to write the names for the elements that have the following symbols: O, S, Cu, Ag.
2. Use the periodic table to write the symbols for the following elements: iron, nitrogen, calcium, mercury.
3. Which elements are most likely to undergo the same kinds of reactions, those in a group or those in a period?
4. Describe the main differences between metals, nonmetals, and metalloids.

CHAPTER 1 REVIEW

CHAPTER SUMMARY

1-1

- Chemistry is the study of the composition, structure, and properties of matter and its changes.
- Chemistry is classified as physical science. Six areas of study in chemistry are organic chemistry, inorganic chemistry, physical chemistry, analytical chemistry, biochemistry, and theoretical chemistry.
- A chemical is any substance that has a definite composition or is used or produced in a chemical process.
- Basic research is carried out for the sake of increasing knowledge. Applied research is carried out to solve practical problems. Technological development involves the use of existing knowledge to make life easier or more convenient.

Vocabulary

chemical (6)
chemistry (5)

1-2

- All matter has mass and takes up space. Mass is one measure of the amount of matter.
- An element is composed of one kind of atom. Compounds are made from two or more elements in fixed proportions.
- All substances have characteristic properties that enable chemists to tell the substances apart and to separate them.
- The physical properties of a substance can be observed or measured without changing the identity of the substance. Physical changes do not involve changes in identity.
- The three major states of matter are solid, liquid, and gas. The particles in these states differ in proximity to one another and ease of flow. Changes of state, such as melting and boiling, are physical changes.
- Chemical properties refer to a substance's ability to undergo changes that alter its composition and identity. Chemical changes, or chemical reactions, involve changes in identity.
- Energy changes accompany physical and chemical changes. Energy may be released or absorbed, but it is neither created nor destroyed.
- Matter can be classified into mixtures and pure substances. Pure substances differ from mixtures in that they have a definite composition that does not vary. Solutions are homogeneous mixtures.

Vocabulary

atom (10)	element (10)	liquid (12)	plasma (12)
change of state (12)	extensive property (11)	mass (10)	product (13)
chemical change (13)	gas (12)	matter (10)	pure substance (17)
chemical property (12)	heterogeneous (16)	mixture (15)	reactant (13)
chemical reaction (13)	homogeneous (16)	physical change (12)	solid (12)
compound (11)	intensive property (11)	physical property (11)	solution (16)

1-3

- Each element has a unique symbol. The periodic table shows the elements organized by their chemical properties. Columns on the table represent groups or families of elements with similar chemical properties. Properties vary across the rows, or periods.
- The elements can be classified as metals, nonmetals, metalloids, and noble gases. These classes occupy different areas of the periodic table. Metals tend to be shiny, malleable, ductile, and good conductors. Nonmetals tend to be brittle and poor conductors. Metalloids are intermediate in properties between metals and nonmetals, and they tend to be semiconductors of electricity. The noble gases are generally unreactive elements.

Vocabulary

family (21)	metal (22)	nonmetal (23)
group (21)	metalloid (24)	period (21)

REVIEWING CONCEPTS

1. What is chemistry? (1-1)
2. What branch of chemistry is most concerned with the study of carbon compounds? (1-1)
3. What is meant by the word *chemical*, as used by scientists? (1-1)
4. Briefly describe the differences between basic research, applied research, and technological development. Provide an example of each. (1-1)
5. a. What is mass?
   b. What is volume? (1-2)
6. How does the composition of a pure compound differ from that of a mixture? (1-2)
7. a. Define *property*.
   b. How are properties useful in classifying materials? (1-2)
8. What is the difference between extensive properties and intensive properties? (1-2)
9. a. Define *physical property*.
   b. List two examples of physical properties. (1-2)
10. a. Define *chemical property*.
    b. List two examples of chemical properties. (1-2)
11. Distinguish between a *physical change* and a *chemical change*. (1-2)
12. a. How does a solid differ from a liquid?
    b. How does a liquid differ from a gas?
    c. How is a liquid similar to a gas?
    d. What is a plasma? (1-2)
13. What is meant by a change in state? (1-2)
14. What is the significance of the vertical columns of the periodic table? What is the significance of the horizontal rows? (1-3)
15. Compare the physical properties of metals, nonmetals, metalloids, and noble gases and describe where in the periodic table each of these kinds of elements is located. (1-3)
16. In which of the six branches of chemistry would a scientist be working if he or she were doing the following: (1-1)
    a. investigating energy relationships for various reactions
    b. comparing properties of alcohols with those of sugars
    c. studying reactions that occur during the digestion of food
    d. carrying out tests to identify unknown substances
17. Identify the reactants and products in the following reaction: (1-2)
    potassium + water ⟶ potassium hydroxide + hydrogen
18. Suppose element *X* is a poor conductor of electricity and breaks when hit with a hammer. Element *Z* is a good conductor of electricity and heat. In what area of the periodic table does each element most likely belong? (1-3)
19. Identify each of the following as either a physical change or a chemical change. Explain your answers. (1-2)
    a. A piece of wood is sawed in half.
    b. Milk turns sour.
    c. Melted butter solidifies in the refrigerator.
20. Use the periodic table to write the names of the elements that have the following symbols, and identify each as a metal, nonmetal, metalloid, or noble gas. (1-3)
    a. K   c. Si   e. Hg
    b. Ag   d. Na   f. He
21. An unknown element is shiny and is found to be a good conductor of electricity. What other properties would you predict for it? (1-3)
22. Identify each of the following as an example of either basic research, applied research, or technological development: (1-1)
    a. A new type of refrigerant is developed that is less damaging to the environment.
    b. A new element is synthesized in a particle accelerator.
    c. A computer chip is redesigned to increase the speed of the computer.
23. Use the periodic table to identify the group numbers and period numbers of the following elements: (1-3)
    a. carbon, C   c. chromium, Cr
    b. argon, Ar   d. barium, Ba

24. a. Suppose different parts of a sample material have different compositions. What can you conclude about the material? (1-2)
  b. Suppose different parts of a sample have the same composition. What can you conclude about the material? Explain your answer. (1-2)

TECHNOLOGY & LEARNING

25. **Graphing Calculator** Graphing Tabular Data

The graphing calculator can run a program that graphs ordered pairs of data, such as temperature versus time. In this problem you will learn how to create a table of data. Then you will learn how to use the program to plot the data.

Go to Appendix C. If you are using a TI 83 Plus, you can download the program and data sets and run the application as directed. If you are using another calculator, your teacher will provide you with keystrokes and data sets to use. Remember that after creating the lists, you will need to name the program and check the display, as explained in Appendix C. You will then be ready to run the program. After you have graphed the data sets, answer these questions.

  a. Approximately what would the temperature be at the 16-minute interval?
  b. Between which two intervals did the temperature increase the most: between 6 and 7 minutes, between 5 and 6 minutes, or between 8 and 9 minutes?
  c. If the graph extended to 20 minutes, what would you expect the temperature to be?

HANDBOOK SEARCH

26. Review the information on trace elements in the *Elements Handbook* in the back of this text.
  a. What are the functions of trace elements in the body?
  b. What transition metal plays an important role in oxygen transport throughout the body?
  c. What two Group 1 elements are part of the electrolyte balance in the body?

RESEARCH & WRITING

27. Research any current technological product of your choosing. Find out about its manufacture and uses. Also find out about the basic research and applied research that made its development possible.

ALTERNATIVE ASSESSMENT

28. Make a list of all the changes that you see around you involving matter during a one-hour period. Note whether each change seems to be a physical change or a chemical change. Give reasons for your answers.

29. Make a concept map using at least 15 terms from the vocabulary lists. An introduction to concept mapping is found in Appendix B of this book.