

## CHAPTER 1

# Matter and Change



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### SECTION 1

Chemistry Is a Physical Science

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Elements

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Chemistry Matters

# Chemistry Is a Physical Science

## Key Terms

chemistry

chemical

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

## ▶ MAIN IDEA

### Chemistry is the study of matter and its processes.

**Chemistry** is the study of the composition, structure, and properties of matter, the processes that matter undergoes, and the energy changes that accompany these processes. Chemistry deals with questions such as: What is a material's makeup? How does a material change when heated, cooled, or mixed with other materials and why does this behavior occur? Chemists answer these kinds of questions during their work.

Instruments like those shown in **Figure 1.1** are routinely used in chemistry to extend our ability to observe and make measurements. They make it possible, for example, to look at microstructures—things too tiny to be seen with the unaided eye. The scanning tunneling microscope reveals tiny structures by beaming extremely small particles called electrons at materials. When the electrons hit a material, they scatter and produce a pattern that shows the material's microstructure.

## Main Ideas

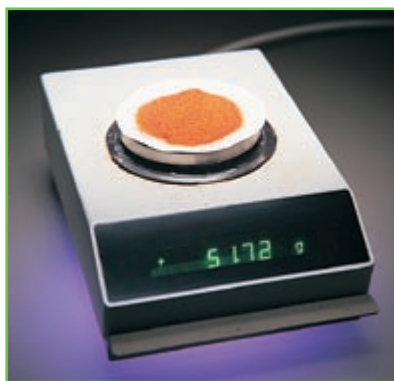
- ▶ Chemistry is the study of matter and its processes.
- ▶ There are several branches of chemistry.

## ▶ VIRGINIA STANDARDS

**CH.1** The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data.  
**CH.1.EKS-1**

FIGURE 1.1

### Scientific Observations



(a) A balance is an instrument used to measure the mass of materials.



(b) A sample of DNA placed in a scanning tunneling microscope produces an image showing the contours of the DNA's surface.

Invisible rays called X-rays can also be used to determine microstructures. The patterns that appear 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.

### ▶ MAIN IDEA

## There are several branches of chemistry.

Chemistry includes many different branches of study and research. The following are six main areas 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 non-organic substances, many of which have organic fragments bonded to metals (organometallics)
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 can often be carried out on a large scale to make new consumer products such as flavor enhancers and fabrics.

### 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, molecular structure, and chemical composition of the new material.

## Applied Research

Applied research is generally carried out to solve a problem. For example, when certain 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 health problems, chemists have developed new refrigerants. In applied research, researchers are driven not by curiosity or a desire to know but by a desire to solve a specific problem.

## 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 discoveries that are eventually used in 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 challenge arose. 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.

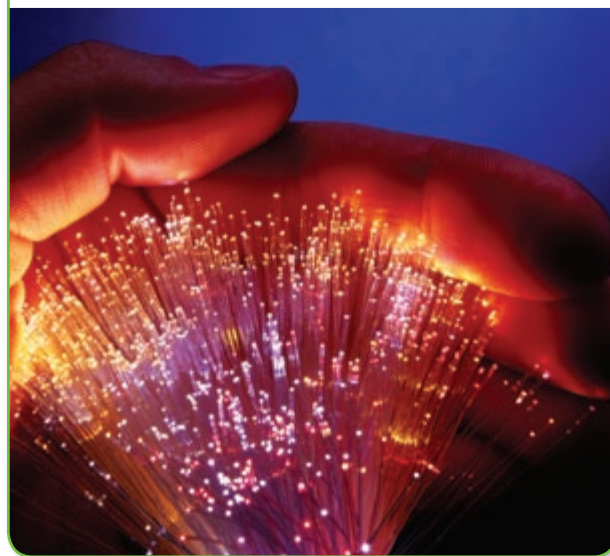
Basic research, applied research, and technological development often overlap. Discoveries made in basic research may lead to applications that can result in new technologies. For example, knowledge of crystals and light that was gained from basic research was used to develop lasers. It was then discovered that pulses of light from lasers can be sent through optical fibers, like the ones shown in **Figure 1.2**. Today, telephone messages and cable television signals are carried quickly over long distances using fiber optics.

## ✓ CHECK FOR UNDERSTANDING

**Apply** Would testing a new drug to find if it is an effective treatment for a disease be considered basic research or applied research? Explain your answer.

FIGURE 1.2

**Applying Research** 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 networks by sending data on light pulses is the technological development of fiber optics.



## SECTION 1 FORMATIVE ASSESSMENT

### ▶ Reviewing Main Ideas

1. Explain what chemistry is.
2. Name six branches of study in chemistry.
3. Compare and contrast basic research, applied research, and technological development.

### ✓ Critical Thinking

4. **INFERRING RELATIONSHIPS** Scientific and technological advances are constantly changing how people live and work. Discuss a change you have observed in your lifetime that has made life easier or more enjoyable for you.



## SECTION 2

### Main Ideas

- ▶ Atoms are the building blocks of matter.
- ▶ All substances have characteristic properties.
- ▶ Matter can be a pure substance or a mixture.

### VIRGINIA STANDARDS

**CH.2.h** The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure. The periodic table is a tool used for the investigations of: chemical and physical properties.

**CH.2.EKS-14; CH.2.EKS-15**

# Matter and Its Properties

## Key Terms

mass	physical change	chemical reaction
matter	change of state	reactant
atom	solid	product
element	liquid	mixture
compound	gas	homogeneous
extensive property	plasma	solution
intensive property	chemical property	heterogeneous
physical property	chemical change	pure substance

All 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.

### ▶ MAIN IDEA

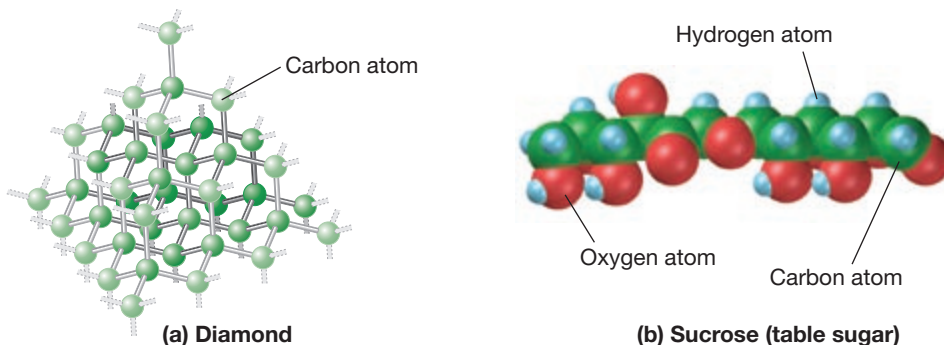
## Atoms are the building blocks of matter.

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 chemical identity of that element. An element is a pure substance that cannot be broken down into simpler, stable substances and is made of one type of atom.** Carbon is an element and contains one kind of atom. The model of diamond in **Figure 2.1a** consists of carbon atoms.

FIGURE 2.1

### Atoms as Building Blocks

Both elements and compounds are made of atoms, as shown in these models of diamond and table sugar.



A **compound** is a substance that can be broken down into simple stable substances. Each compound is made from the atoms of two or more elements that are chemically bonded. Sucrose, in **Figure 2.1b**, is an example of a compound. It is made of three elements: carbon, hydrogen, and oxygen. The atoms are chemically bonded to form a molecule. You will learn more about the particles that make up compounds when you study chemical bonding. 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.

## ▶ MAIN IDEA

### All substances have characteristic properties.

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, many elements are classified as 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 to transfer energy as heat. Intensive properties are the same for a given substance regardless of how much of the substance is present. For example, iron melts at 1538°C regardless of whether or not you have 20 g or 20 kg of it. 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. We commonly use physical properties to describe a substance. Examples of physical properties are melting point and boiling point. For example, water melts from ice to liquid at 0°C (273 K or 32°F). Liquid water, as shown in **Figure 2.2**, boils to vapor at 100°C (373 K or 212°F). Density is also another physical property. Water's density at 4°C (277 K or 39°F) is about 1000 kg/m<sup>3</sup>. Unlike most substances, the density of water decreases when it freezes to become ice. As a result, a pond or lake that freezes in the winter does so from the top down, enabling some fish to survive in the water at the bottom.

FIGURE 2.2

**Physical Properties** Water boils at 100°C. This is an example of a physical property.

#### ✔ CRITICAL THINKING

**Classify** Is the boiling point of water an extensive or an intensive property? Explain.



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.

### States of Matter

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. **Figure 2.3** shows the differences between the three states of matter at the molecular level.

**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 the strong attractive forces between them, and only vibrate about fixed points. The amount of attraction varies with different solids. This accounts for some solids being more easily compressible.

**FIGURE 2.3**

### Modeling States of Matter

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.



**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 the strong attractive forces between them and 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 have a lesser effect than they do at the small distances between particles of liquids and solids.

An important fourth state of matter is plasma. **Plasma is a high-temperature physical state of matter in which atoms lose most of their electrons, particles that make up atoms.** Plasma is found in fluorescent bulbs.

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. 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.

## 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. 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 carbon dioxide gas. After the chemical change, the amounts of the original substances, carbon and oxygen, are not less than before. They simply have recombined to form different substances with different properties. **Figure 2.4** shows how a chemical property of a substance known as Benedict's solution is used to test for sugars in urine.

**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, a gas, and ashes are the products, which are clearly different from the reactants.

**FIGURE 2.4**

**Chemical Properties** Because Benedict's solution possesses certain chemical properties, a test strip containing it 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.





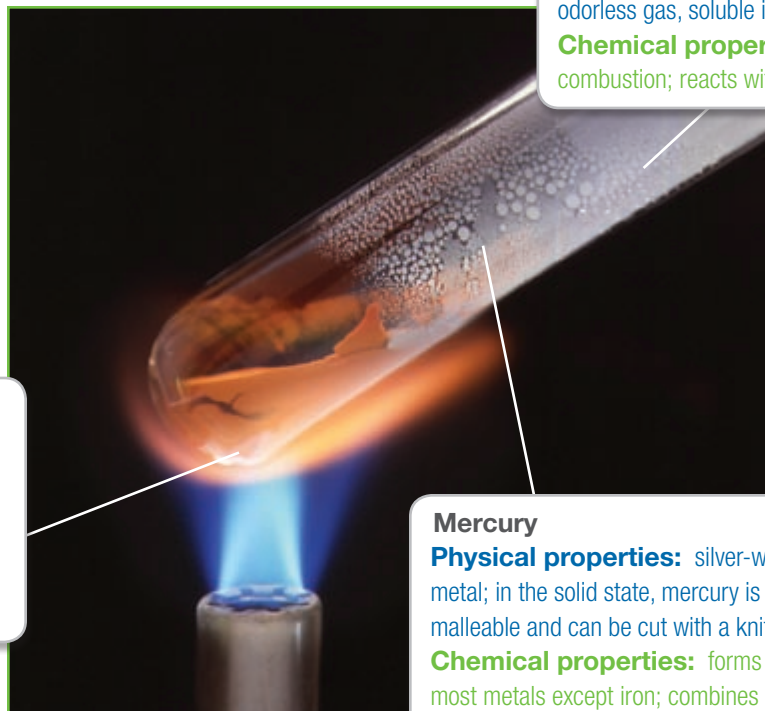
FIGURE 2.5

**Chemical Changes** 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.

**Mercury(II) oxide**

**Physical properties:** bright red or orange-red, odorless crystalline solid, almost insoluble in water

**Chemical properties:** decomposes when exposed to light or at 500°C to form mercury and oxygen gas



**Oxygen**

**Physical properties:** colorless, odorless gas, soluble in water

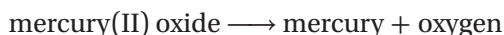
**Chemical properties:** supports combustion; reacts with many metals

**Mercury**

**Physical properties:** silver-white, liquid metal; in the solid state, mercury is ductile and malleable and can be cut with a knife

**Chemical properties:** forms alloys with most metals except iron; combines readily with sulfur at normal temperatures; reacts with nitric acid and hot sulfuric acid; oxidizes to form mercury(II) oxide upon heating

Chemical reactions are normally written with arrows and plus signs. These stand for the words *yields* and *plus*, respectively. For example, to describe the decomposition of the mercury compound shown in Figure 2.5, we'd write it as follows:



In other words, mercury(II) oxide *yields* mercury *plus* oxygen.

Although chemical reactions form products whose properties can differ greatly from those of the reactants, they do not affect the total amount of matter present before and after a reaction. The law of conservation of mass is always followed in chemical reactions.

### 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, although 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. The boundaries can sometimes be confusing!

**✓ CHECK FOR UNDERSTANDING**

**Explain** An antacid tablet is dropped into a glass of water and dissolves. The tablet fizzes, and bubbles of gas rise to the surface. Is this a physical change or a chemical change? Explain your answer.

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. 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.

▶ **MAIN IDEA**

## Matter can be a pure substance or a mixture.

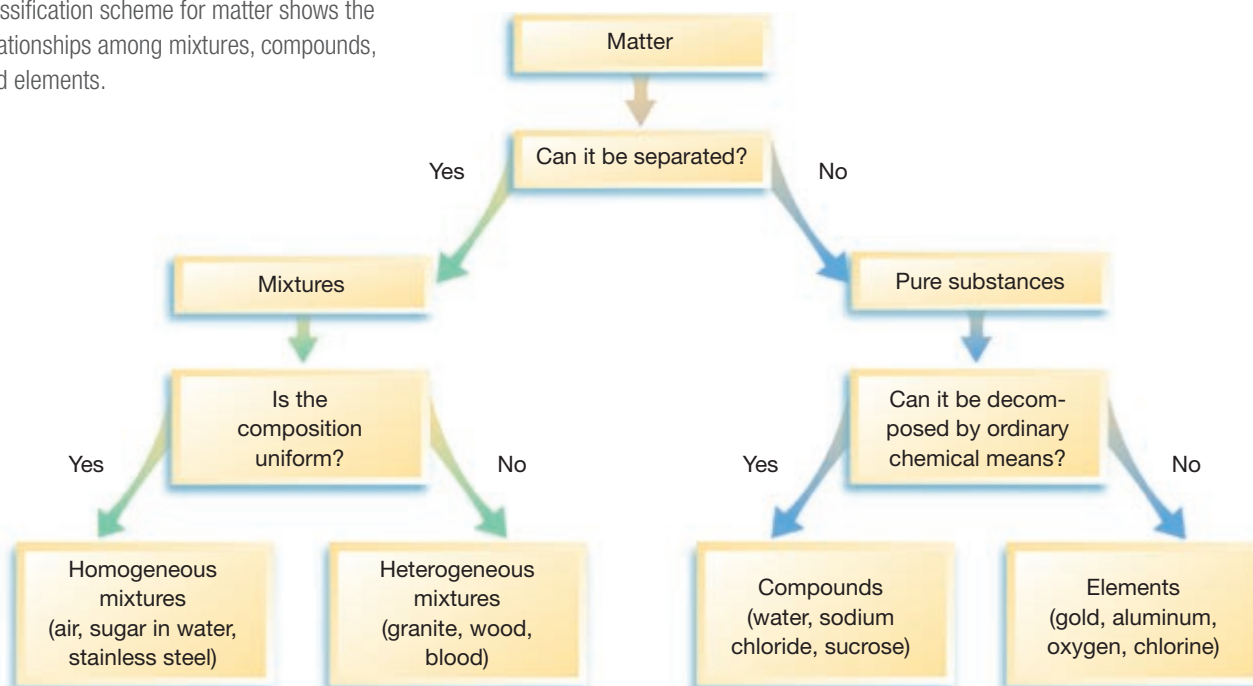
Matter exists in an enormous variety of forms. Any sample of matter, however, can be classified either as a pure substance or as a mixture. The composition of a pure substance is the same throughout and does not vary from sample to sample. A pure substance can be an element or a compound. Mixtures, in 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 2.6** 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. Mixtures can be very simple or very complex, and they can have some unique properties.

**FIGURE 2.6**

**Classification of Matter** This classification scheme for matter shows the relationships among mixtures, compounds, and elements.



**FIGURE 2.7**

## Separating Mixtures



**(a) Filtration** Barium chromate can be separated from the solution in the beaker using filtration.



**(b) Using a Centrifuge** 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.

### **CRITICAL THINKING**

**Classify** Would the mixtures shown in the photos be defined as homogeneous or heterogeneous? Explain.



**(c) Chromatography** The components of an ink can be separated using paper chromatography.

**A mixture is a blend of two or more kinds of matter, each 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.

**Mixtures that are uniform in composition 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. **Mixtures that are not uniform throughout are said to be 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. In **Figure 2.7a**, 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 2.7b**) 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 move at different rates on the paper (**Figure 2.7c**).

## Pure Substances

A **pure substance** has a **fixed composition**. Pure substances are always homogeneous. They differ from mixtures in the following ways:

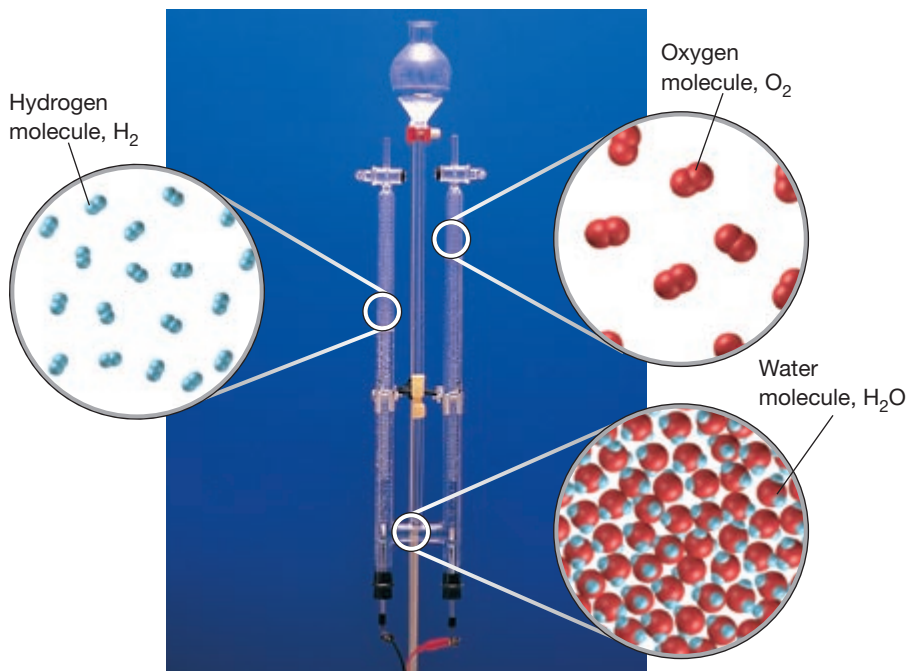
1. *Every sample of a given pure substance has exactly the same characteristic properties.* All samples of a pure substance have the same characteristic physical and chemical properties. These properties are so specific that they can be used to identify the substance. In contrast, the properties of a mixture depend on the relative amounts of the mixture's components.
2. *Every sample of a pure substance has exactly the same composition.* 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 made of hydrogen and oxygen chemically bonded to form a single substance. Water can be broken down into hydrogen and oxygen through electrolysis, as shown in **Figure 2.8a**.

Sucrose is made of carbon, hydrogen, and oxygen. Sucrose breaks down under intense heating, to produce carbon and water (**Figure 2.8b**). This is of particular delight to anyone with a sweet tooth!

FIGURE 2.8

### Decomposition of Compounds



**(a) Separation by Electrolysis** 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) Decomposition by Heating** When sucrose is heated, it caramelizes. When it is heated to a high enough temperature, it breaks down completely into carbon and water.



FIGURE 2.9

### 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. The purity ranking of the grades can vary with different agencies, as seen in **Figure 2.9**. 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. The chemical manufacturer must ensure that the standards set for that reagent by the American Chemical Society (A.C.S.) are met. Reading and understanding the labels placed on chemicals, like those shown in **Figure 2.10**, is a crucial skill for chemists.

FIGURE 2.10

**Chemical Purity** The labeling on this bottle lists the grade of the reagent (a) and the percentages of impurities for that grade (b). What grade is this chemical?



(a)

$\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  F.W. 297.47

**Certificate of Actual Lot Analysis**

Acidity (as $\text{HNO}_3$ )	0.008%
Alkalies and Earths	0.02%
Chloride (Cl)	0.005%
Insoluble Matter	0.001%
Iron (Fe)	0.0002%
Lead (Pb)	0.001%
Phosphate ( $\text{PO}_4$ )	0.0002%
Sulfate ( $\text{SO}_4$ )	0.002%

Store separately from and avoid contact with combustible materials. Keep container closed and in a cool, dry place. Avoid contact with skin, eyes and clothing.

LOT NO. 917356

FL-02-0588 CAS 10196-18-6



## SECTION 2 FORMATIVE ASSESSMENT

### ▶ Reviewing Main Ideas

- What is the main difference between physical properties and chemical properties?
  - Give an example of each.
- Classify each of the following as either a physical change or a chemical change.
  - tearing a sheet of paper
  - melting a piece of wax
  - burning a log

- How do you decide whether a sample of matter is a solid, a liquid, or a gas?
- Contrast mixtures with pure substances.

### ✓ Critical Thinking

- ANALYZING INFORMATION** Compare the composition of sucrose purified from sugar cane with the composition of sucrose purified from sugar beets. Explain your answer.

## Secrets of the Cremona Violins

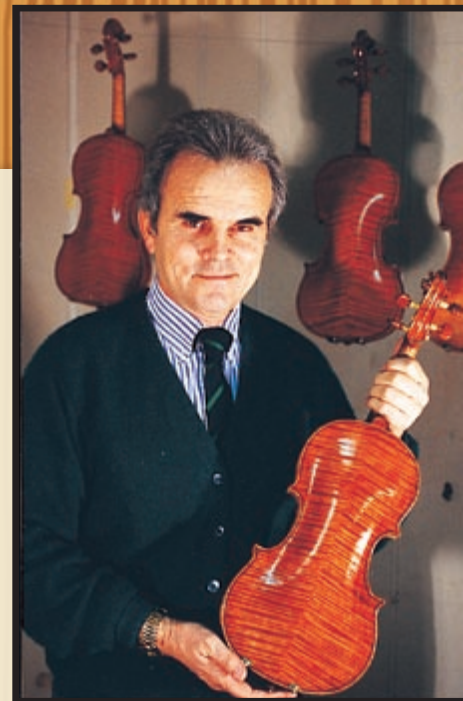
**W**hat are the most beautiful-sounding of all violins? Most professionals will pick the instruments created in Cremona, Italy, between the 16th and 18th centuries. At that time, Antonio Stradivari, members of the Guarneri family, and other designers created instruments of extraordinary sound that have 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.

According to Dr. Nagyvary, instruments made by Stradivari 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 seawater. Dr. Nagyvary first theorized that the soaking process could have removed ingredients from the wood that made it inherently noisy. Images taken with a scanning electron microscope showed a slimy fungus growing on the wood. Dr. Nagyvary's experiments revealed that the fungus released enzymes that destroyed a structural material in the plants, called hemicellulose. Attempting to reproduce the effects of seawater, 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 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.



*Dr. Nagyvary and his violin*

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, almost everyone agrees that the art and science of violin making are still epitomized by the instruments of Cremona.

### Questions

1. According to Dr. Nagyvary, what are two factors that are believed to have created the unique sound of the Stradivari violins?
2. What technology did Dr. Nagyvary use in his experiments to recreate the violins?
3. Use the library or Internet resources to find additional information about the Cremona violin makers. Who were some of the other instrument makers during the time period in which Stradivari was alive? Were other stringed instruments made by these artisans? What are the estimated present-day values of instruments made during this period in Cremona?

## SECTION 3

### Main Ideas

- ▶ The periodic table organizes elements by their chemical properties.
- ▶ Some elements are metals.
- ▶ Some elements are nonmetals or metalloids.

### VIRGINIA STANDARDS

CH.2 The student will investigate and understand that the placement of elements on the periodic table is a function of their atomic structure.

CH.2.EKS-7; CH.2.EKS-8

# Elements

## Key Terms

group  
family

period  
metal

nonmetal  
metalloid

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 3.2** on the next page.

### ▶ MAIN IDEA

## The periodic table organizes elements by their chemical properties.

Each small square of the periodic table shows the symbol for an element and its atomic number. For example, the first square, at the upper left, represents element 1, hydrogen, which has the 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 an element's symbol to its English name. Some symbols come from the element's older name, which was often in Latin. Still others come from German. For example, the symbol W for tungsten comes from its German name, wolfram. **Figure 3.1** lists some elements and their older names.

FIGURE 3.1

### 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



FIGURE 3.2

**The Periodic Table** The names of the elements can be found in the larger periodic table inside the back cover of your book.

PREMIUM  
CONTENT

**Animated**  
Chemistry



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The Organization of the  
Periodic Table

Group 1		Group 2												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 Ds	111 Rg	112 Cn									
			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				

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 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* (Appendix A) which covers some elements in greater detail. You will use information from the handbook to complete the questions in the *Using the Handbook* sections in the chapter reviews.



## WHY IT MATTERS

### Superconductors **S.T.E.M.**

Any metal becomes a better conductor of electrical energy as its temperature decreases. In 1911, scientists discovered that when mercury is cooled to about  $-269^{\circ}\text{C}$ , it loses all resistance and becomes a superconductor. Scientists have long tried to find a material that would superconduct at temperatures above  $-196^{\circ}\text{C}$ , the boiling point of liquid nitrogen. In 1987, scientists discovered ceramic materials that became superconductors when cooled only to  $-183^{\circ}\text{C}$ . These “high-temperature” superconductors are used to build very powerful electromagnets. Ceramic electromagnets are used in medical magnetic resonance imaging (MRI) machines and in high-efficiency electric motors and generators.

## MAIN IDEA

### Some elements are metals.

The periodic table is broadly divided into two main sections: metals and nonmetals. As you can see in **Figure 3.2** on the previous page, the metals are at the left and in the center of the table. The nonmetals are toward the right. Some elements, such as boron and silicon, show characteristics of both metals and nonmetals.

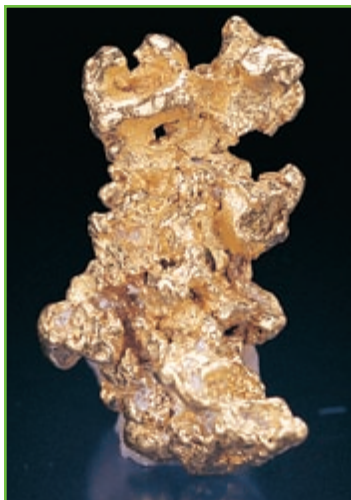
Some of the properties of metals may be familiar to you. For example, you can recognize metals by their shininess, or metallic luster. Perhaps the most important characteristic property of metals is the ease with which they conduct electricity and transfer energy. **Thus, a metal is an element that is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

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, such as 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 3.3** shows three examples of metals: gold, copper, and aluminum.

FIGURE 3.3

### Characteristic Properties of Metals



(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 conducts electrical energy.



(c) Aluminum is malleable. It can be rolled into foil that is used for wrapping food.

Copper, shown in **Figure 3.3b**, 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 also an essential mineral in the human diet.

**✓ CHECK FOR UNDERSTANDING**

Mercury is a metal that is liquid at room temperature. Using the Elements Handbook (Appendix A) as a reference, are there any non-metals that are liquids at room temperature?

**▶ MAIN IDEA**

**Some elements are nonmetals or metalloids.**

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 3.4**.

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 the periodic table, you will see that there are fewer nonmetals than metals.

Phosphorus, shown in **Figure 3.4c**, 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 at room temperature, white phosphorus is stored under water. 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 3.4**

**Nonmetallic Elements**



**FIGURE 3.5**

**Noble Gases** Some noble gases are used to make lighted signs of various colors.



The elements in Group 18 of the periodic table are the noble gases. These elements are generally unreactive, although some can be made to form compounds, such as xenon hexafluoroplatinate. Low reactivity makes the noble gases very different from the other families of elements. Group 18 elements are gases at room temperature. Neon, argon, krypton, and xenon are all used to make lighted signs, like the one in **Figure 3.5**.

As you look from left to right on the periodic table, you can see that the metalloids are found between the metals and the nonmetals. **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 solid state circuitry found in desktop computers, digital watches, televisions, and radios.



## SECTION 3 FORMATIVE ASSESSMENT

### ▶ Reviewing Main Ideas

1. Use the periodic table to write the names for the following elements: 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.

### ✓ Critical Thinking

5. **INFERRING CONCLUSIONS** If you find an element in nature in its pure elemental state, what can you infer about the element's chemical reactivity? How can you tell whether that element is a metal or a nonmetal?

SI units of measurement are based on multiples of 10, making them much easier to work with mathematically than the unrelated units of the U.S. standard measurements like ounces, pounds, feet, and gallons. Most calculations with SI units can

be converted from one unit to another simply by moving the decimal point.

For example, look at the illustration below.

$10^3$ m	$10^2$ m	$10^1$ m	$10^0$ m	$10^{-1}$ m	$10^{-2}$ m	$10^{-3}$ m
kilo	hecto	deka	<u>Base Unit</u>	deci	centi	milli
king	harry	drools	ugly	dark	chocolate	milk

To convert the SI base unit for distance, meters, to centimeters, the decimal point is simply moved 2 spaces to

the right. One meter is equal to 100 centimeters.

### Problem-Solving TIPS

- Make note of the unit that is given at the beginning of the problem and check to see if the answer you are seeking is given in the same or a different unit.
- Is the unit given at the beginning an SI base unit, or does it have a prefix?
- If you are converting from a smaller unit to a larger unit, the decimal point will move to the left.
- If you are converting from a larger unit to a smaller unit, the decimal point will move to the right.
- The number of places you move the decimal point is equal to the power of 10 that is indicated by the prefix.
- If you are converting from a unit with a prefix back to a base unit, start with the prefix unit. Make note of the power of 10 of that prefix in the table in your text.
- Check your final unit to see if it makes sense in terms of the answer sought. For example, if you are measuring the length of a tablet, an answer in tens of kilometers would not be appropriate.

### Sample

#### How many liters are there in 9.844 mL?

The prefix *milli* has a power of 10 of  $-3$ . It is therefore smaller than the base unit of liters. Because you are converting from a smaller unit (mL) to a larger unit (L), move the decimal point 3 places to the left:  
 $9.844 \text{ mL} = 0.009844 \text{ L}$

#### Convert 0.35543 km into meters.

The power of 10 for the prefix *kilo* is 3. It is therefore a larger value than the base unit of meters. To convert from a larger unit (km) to a smaller unit (m), move the decimal point 3 places to the right:  
 $0.35543 \text{ km} = 355.43 \text{ m}$





## SECTION 1 Chemistry Is a Physical Science

### KEY TERMS

- Chemistry is the study of the composition, structure, and properties of matter and the changes that matter undergoes.
- 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.

chemistry  
chemical

## SECTION 2 Matter and Its Properties

### KEY TERMS

- All matter has mass and takes up space. Mass is one measure of the amount of matter.
- Chemical properties refer to a substance's ability to undergo changes that alter its composition and identity.
- 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 the substances.
- Physical changes do not involve changes in identity of a substance.
- The three major states of matter are solid, liquid, and gas. Changes of state, such as melting and boiling, are physical changes.
- In a chemical change—or a chemical reaction—the identity of the substance changes.
- 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.

mass  
matter  
atom  
element  
compound  
extensive property  
intensive property  
physical property  
physical change  
change of state  
solid  
liquid

gas  
plasma  
chemical property  
chemical change  
chemical reaction  
reactant  
product  
mixture  
homogeneous solution  
heterogeneous pure substance

## SECTION 3 Elements

### KEY TERMS

- 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 that have 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, and ductile and tend to be good conductors. Nonmetals tend to be brittle and tend to be poor conductors.
- Metalloids are intermediate in properties between metals and nonmetals. They are semiconductors. The noble gases are generally unreactive.

group  
family  
period  
metal  
nonmetal  
metalloid

# CHAPTER 1 Review

## SECTION 1

### Chemistry Is a Physical Science

#### REVIEWING MAIN IDEAS

1. What is chemistry?
2. What branch of chemistry is most concerned with the study of carbon compounds?
3. What is meant by the word *chemical*, as used by scientists?
4. In which of the six branches of chemistry would a scientist be working if he or she were doing the following:
  - 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
5. Identify each of the following as an example of either basic research, applied research, or technological development:
  - a. A new type of refrigerant that is less damaging to the environment is developed.
  - b. A new element is synthesized in a particle accelerator.
  - c. A computer chip is redesigned to increase the speed of the computer.

## SECTION 2

### Matter and Its Properties

#### REVIEWING MAIN IDEAS

6.
  - a. What is mass?
  - b. What is volume?
7. How does the composition of a pure compound differ from that of a mixture?
8.
  - a. Define property.
  - b. How are properties useful in classifying materials?
9. What is the difference between extensive properties and intensive properties?

10.
  - a. Define chemical property.
  - b. List two examples of chemical properties.
11. Distinguish between a physical change and a chemical change.
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?
13. What is meant by a change in state?
14. Identify the reactants and products in the following reaction:  
potassium + water  $\longrightarrow$   
potassium hydroxide + hydrogen
15. Suppose different parts of a sample material have different compositions. What can you conclude about the material?

## SECTION 3

### Elements

#### REVIEWING MAIN IDEAS

16. What is the significance of the vertical columns of the periodic table? What is the significance of the horizontal rows?
17. 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.
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?
19. 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.
  - a. K
  - b. Ag
  - c. Si
  - d. Na
  - e. Hg
  - f. He

20. An unknown element is shiny and is found to be a good conductor of electricity. What other properties would you predict for it?
21. Use the periodic table to identify the group numbers and period numbers of the following elements:
- carbon, C
  - argon, Ar
  - chromium, Cr
  - barium, Ba

## Mixed Review

### REVIEWING MAIN IDEAS

22. a. Define physical property.  
b. List two examples of physical properties.
23. How can you tell the difference between an element and a compound?
24. Identify each of the following as either a physical change or a chemical change. Explain your answers.
- A piece of wood is sawed in half.
  - Milk turns sour.
  - Melted butter solidifies in the refrigerator.
25. Write a brief paragraph that shows that you understand the following terms and the relationships between them: *atom*, *molecule*, *compound*, and *element*.
26. Pick an object you can see right now. List three of the object's physical properties that you can observe. Can you also observe a chemical property of the object? Explain your answer.

### CRITICAL THINKING

27. **Interpreting Concepts** One way to make lemonade is to start by combining lemon juice and water. To make the lemonade taste better you could add some sugar. Is your lemonade-sugar combination classified as a compound or a mixture? Explain your answer.
28. **Analyzing Results** A pure white, solid material that looks like table salt releases gas when heated under certain conditions. There is no change in the appearance of the solid, but the reactivity of the material changes.
- Did a chemical or physical change occur? How do you know?
  - Was the original material an element or a compound?

### Interpreting Concepts

- Is breaking an egg an example of a physical or chemical change? Explain your answer.
- Is cooking an egg an example of a physical or chemical change? Explain your answer.

### USING THE HANDBOOK

30. Review the information on trace elements in the *Elements Handbook* (Appendix A).
- What are the functions of trace elements in the body?
  - What transition metal plays an important role in oxygen transport throughout the body?
  - What two Group 1 elements are part of the electrolyte balance in the body?

### RESEARCH AND WRITING

31. 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.
32. Investigate current and proposed technological applications of superconductors. Find out which of these applications have been successfully tested or are already in use.

### ALTERNATIVE ASSESSMENT

33. During a 1 h period, make a list of all the changes that you see around you and that involve matter. Note whether each change seems to be a physical change or a chemical change. Give reasons for your answers.
34. Make a concept map using at least 15 terms from the vocabulary lists. An introduction to concept mapping is found in the *Study Skills Handbook* of this book.

# Standards-Based Assessment

Answer the following items on a separate piece of paper.

## MULTIPLE CHOICE

- Magnesium reacts with hydrochloric acid to produce magnesium chloride and hydrogen gas. The reactants in this reaction are
  - magnesium and magnesium chloride.
  - hydrochloric acid and hydrogen gas.
  - magnesium and hydrochloric acid.
  - magnesium chloride and hydrogen gas.
- Matter that has a definite shape and a definite volume is
  - a liquid.
  - an element.
  - a solid.
  - a gas.
- We know that air is a mixture and not a compound because
  - it can be heated to a higher temperature.
  - it can be compressed to a smaller volume.
  - it is colorless.
  - its composition can vary.
- Matter can be defined as anything that
  - has weight.
  - has mass and volume.
  - is uniform throughout.
  - exhibits both chemical and physical properties.
- Which of the following is best classified as a homogeneous mixture?
  - pizza
  - blood
  - hot tea
  - copper wire
- A compound differs from a mixture in that a compound
  - contains only one element.
  - varies in chemical composition depending on the sample size.
  - has a definite composition by mass of the elements that the compound contains.
  - can be classified as either heterogeneous or homogeneous.
- Which of the following is *not* a physical state of matter?
  - solid
  - gas
  - element
  - liquid

- Three of the following must contain two or more kinds of atoms. Which one does *not* contain two or more kinds of atoms?
  - element
  - compound
  - homogeneous mixture
  - heterogeneous mixture
- Which of the following symbols does *not* match the element name given?
  - Al, aluminum
  - Co, copper
  - K, potassium
  - P, phosphorus

## SHORT ANSWER

- Give three examples of mixtures, and tell whether each one is homogeneous or heterogeneous. Give three examples of compounds.
- In trying to identify a sample of a pure substance, we observe the following properties. Tell whether each one is a chemical property or a physical property.
  - Its mass is 124.3 g.
  - It is a shiny solid at room temperature.
  - It is easily etched by nitric acid.
  - It melts when heated to 670°C.
  - It is 31.7 centimeters long.
  - It is a good heat conductor.
  - It burns in air.
  - It is a good conductor of electrical energy.

## EXTENDED RESPONSE

- Describe the difference between a chemical change and a physical change. Give one example of each kind of change.
- Describe general properties of metals, nonmetals, and metalloids.



### Test Tip

Remember that if you can eliminate two of the four answer choices, your chances of choosing the correct answer choice will double.