

Chemistry Is a Physical Science

SECTION 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 consist of chemical structures, 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, 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 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 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)

determine 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 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. Today, telephone messages and cable television signals are carried quickly over long distances using fiber optics.

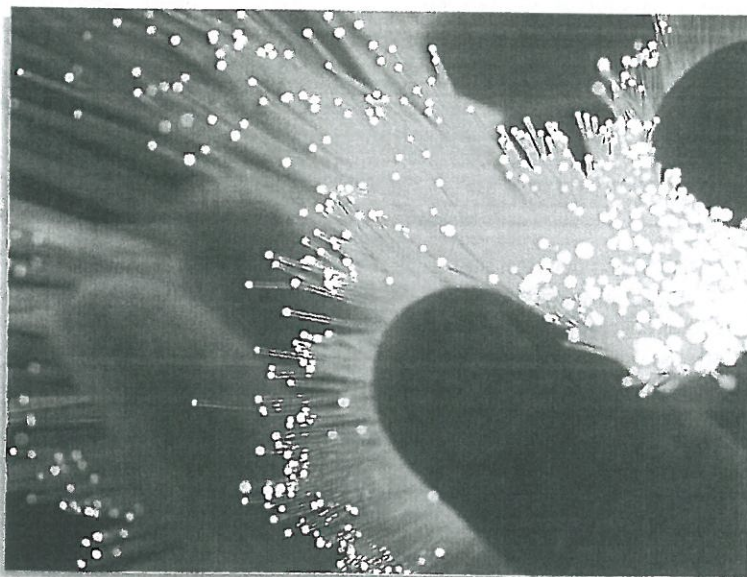


FIGURE 2 The chemical structure of the material in an optical fiber gives it the property of total internal reflection. This property, which allows these fibers to carry light, was discovered through basic and applied research. The use of this property to build networks by sending data on light pulses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

SECTION REVIEW

1. Define *chemistry*.
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 that you have observed in your lifetime and that has made life easier or more enjoyable for you.

SECTION 2

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.
- Explain how the law of conservation of energy applies to changes of matter.
- Distinguish between a mixture and a pure substance.

Matter and Its Properties

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

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.

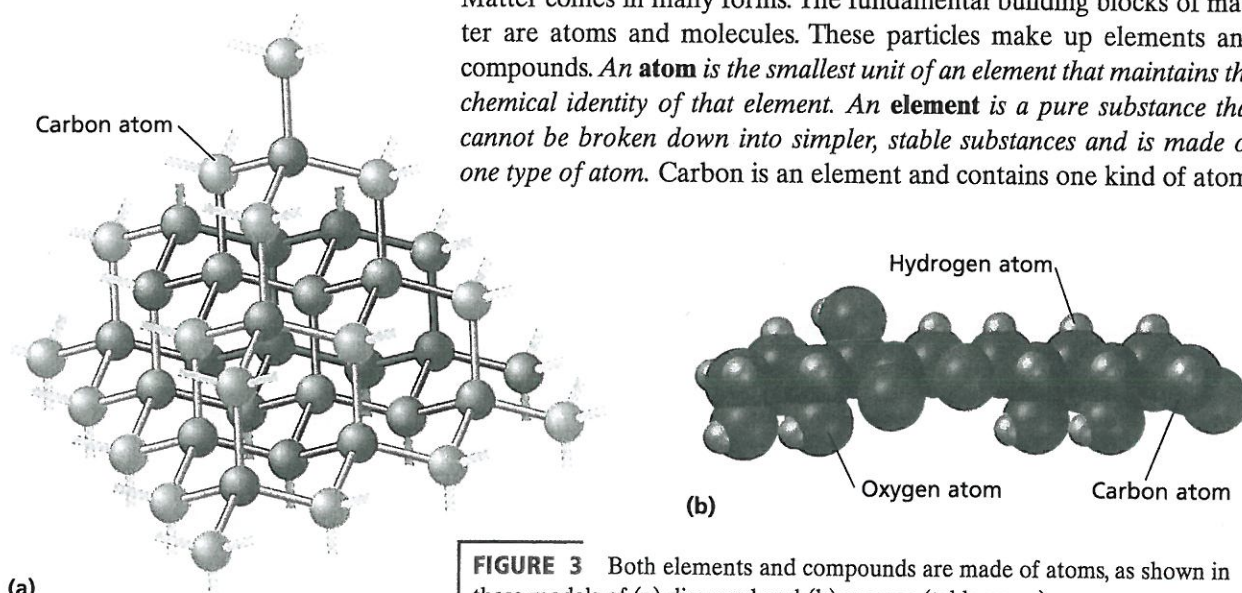


FIGURE 3 Both elements and compounds are made of atoms, as shown in these models of (a) diamond and (b) sucrose (table sugar).

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. 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 set 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. 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).

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

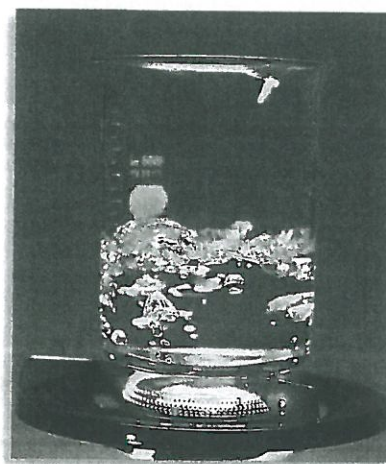


FIGURE 4 Water boils at 100°C no matter how much water is in the container. Boiling point is an intensive property.

SCILINKS

www.scilinks.org

Topic: Physical/Chemical
Changes

Code: HC61145

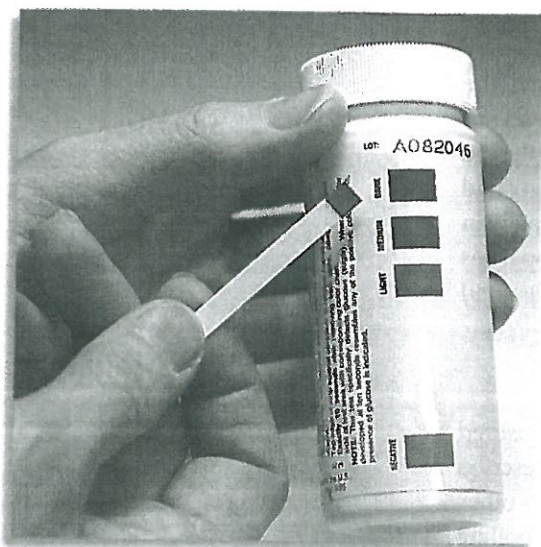


FIGURE 5 Because it possesses certain chemical properties, a test strip containing Benedict's solution is used to test for the presence of sugar in urine. The test strip is dipped into the sample. The test strip is then matched to a color scale to determine the sugar level in the urine.

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 the 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 strong 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 have less of an 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, as shown in **Figure 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.

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

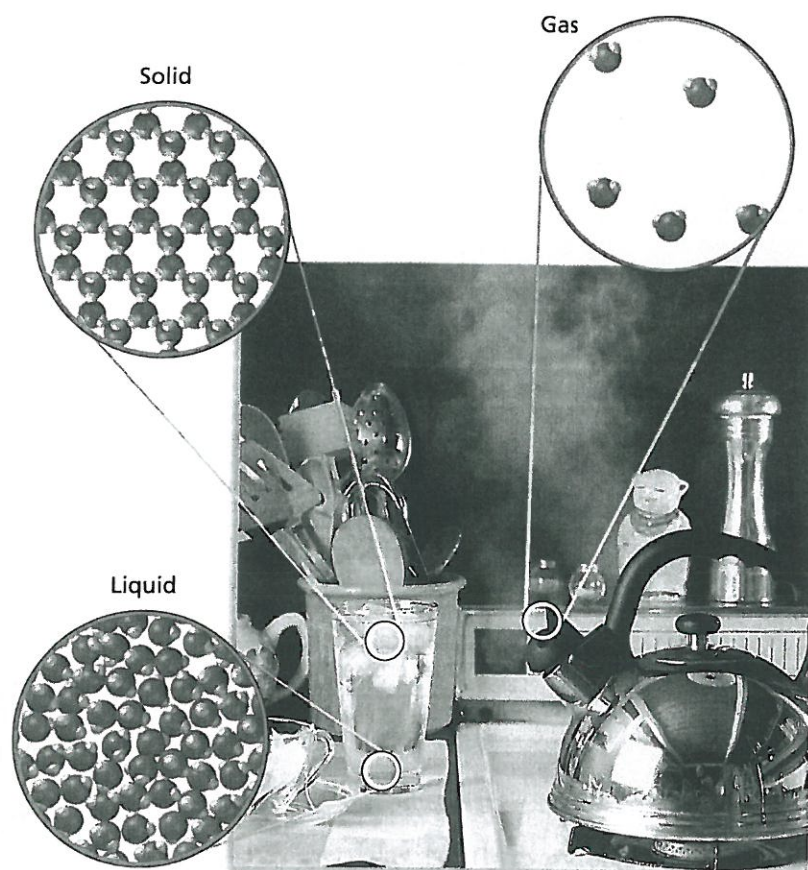


FIGURE 6 Models for water in three states. The molecules are close together in the solid and liquid states but far apart in the gas state. The molecules in the solid state are relatively fixed in position, but those in the liquid and gas states can flow around each other.

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 a new substance, carbon dioxide gas. After the chemical change, the amounts of the original substances, carbon and oxygen, are less than before. 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:



extension

Historical Chemistry

Go to go.hrw.com for a full-length article on the chemical reactions of noble gases.

 Keyword: HC6MTXX

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

Oxygen

Physical properties: colorless, odorless gas, soluble in water
Chemical properties: supports combustion; reacts with many metals

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

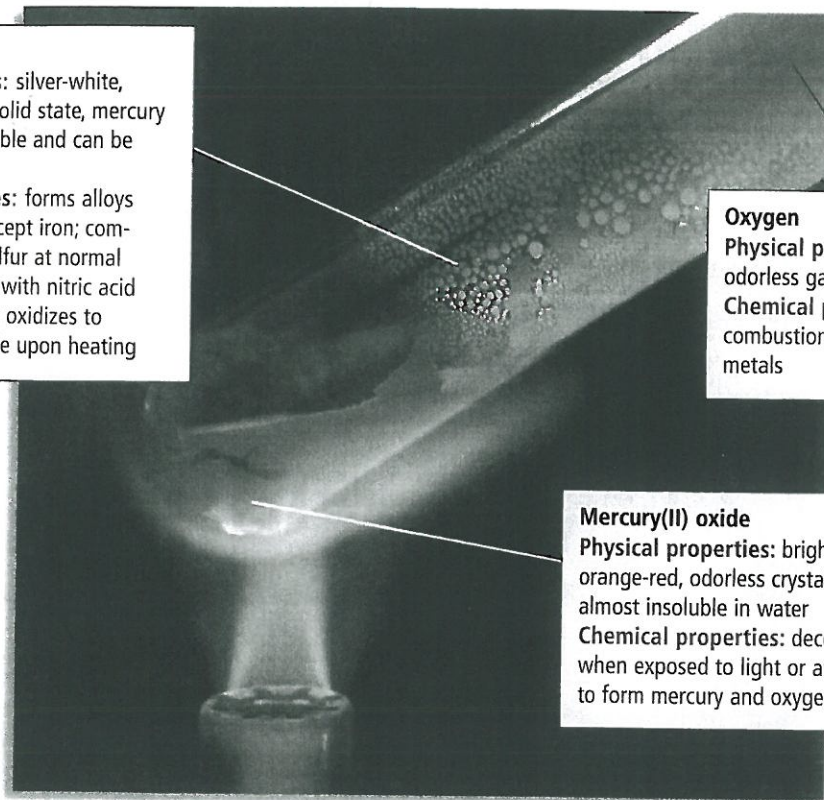


FIGURE 7 When mercury(II) oxide is heated, it decomposes to form oxygen gas and mercury (which can be seen on the side of the test tube). Decomposition is a chemical change that can be observed by comparing the properties of mercury(II) oxide, mercury, and oxygen.

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



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.

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.

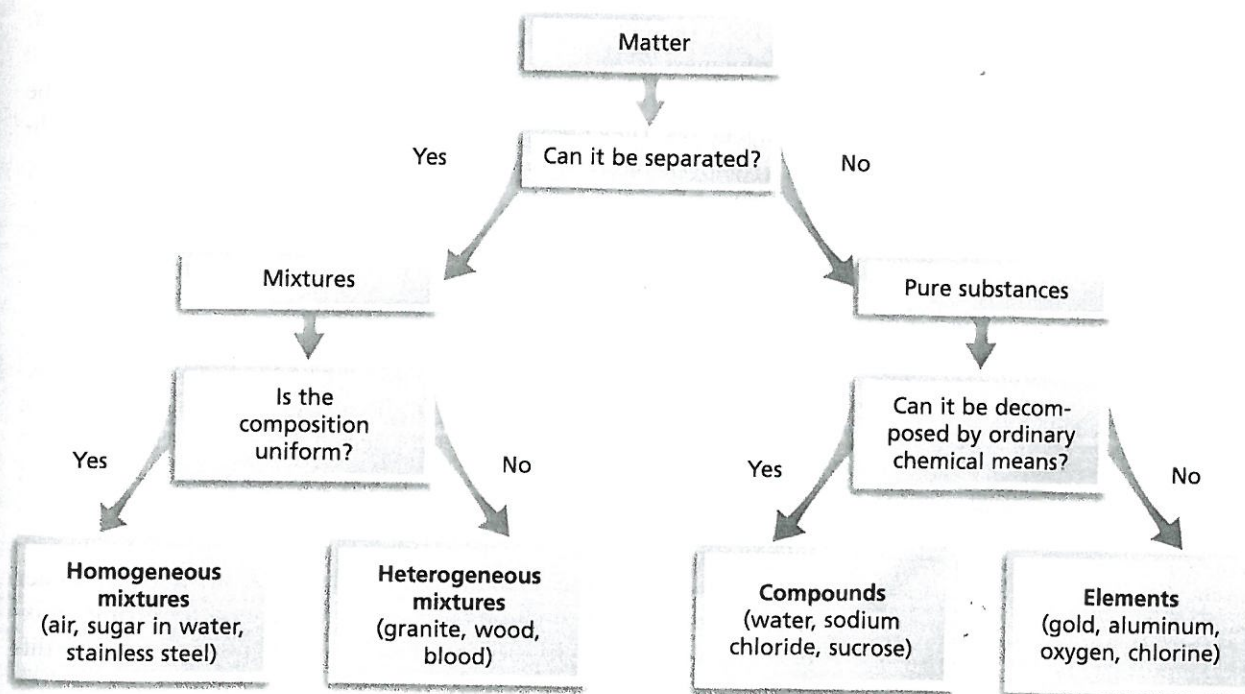
Classification of Matter

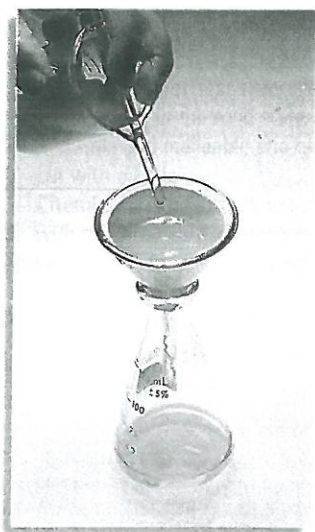
Matter exists in an enormous variety of forms. Any sample of matter, however, can be classified either as a pure substance or as a mixture. The composition of a pure substance is the same throughout and does not vary from sample to sample. A pure substance can be an element or a compound. Mixtures, in 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 8** illustrates the overall classification of matter into elements, compounds, and mixtures.

Mixtures

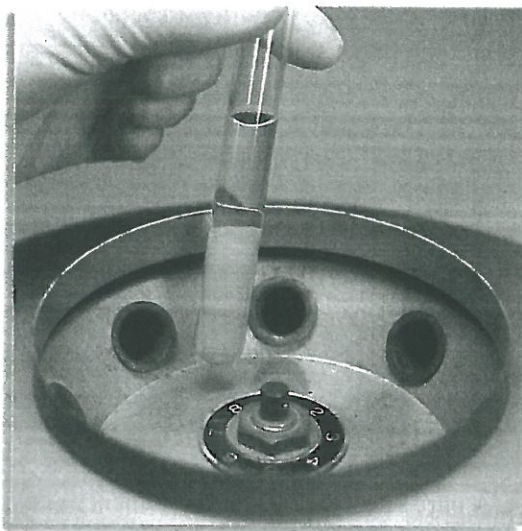
You deal with mixtures every day. Nearly every object around you, including most things you eat and drink and even the air you breathe, is a mixture. A **mixture** is a blend of two or more kinds of matter, each

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

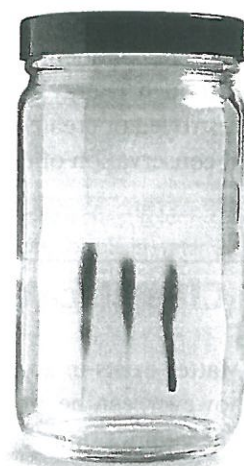




(a)



(b)



(c)

FIGURE 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 9a**. 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 9b**) 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 9c**).

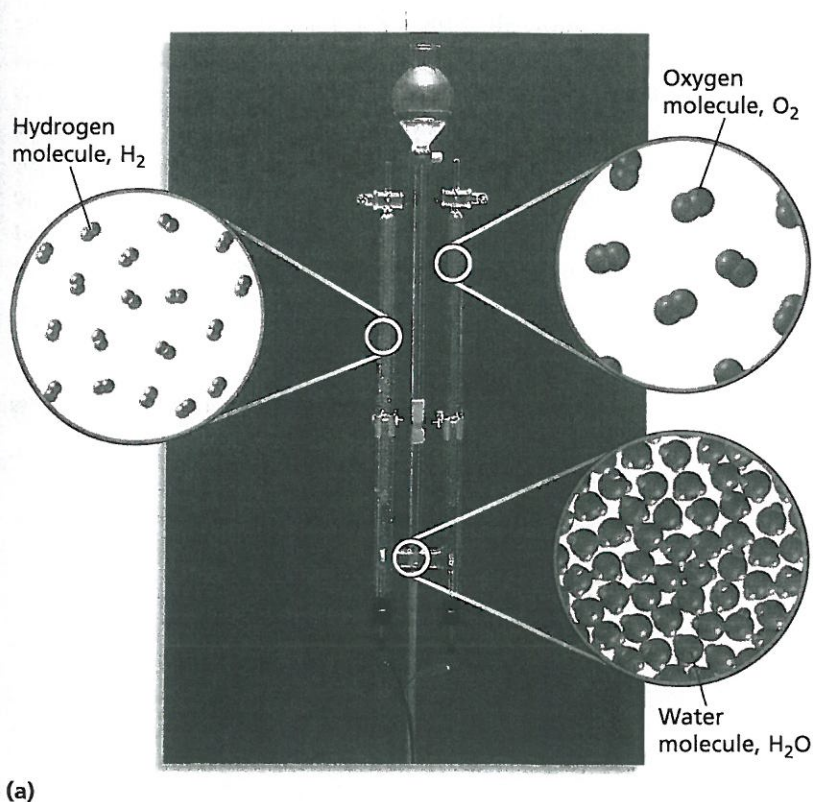
Pure Substances

Any sample of a pure substance is homogeneous. 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 10a**.

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



(a)

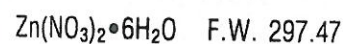
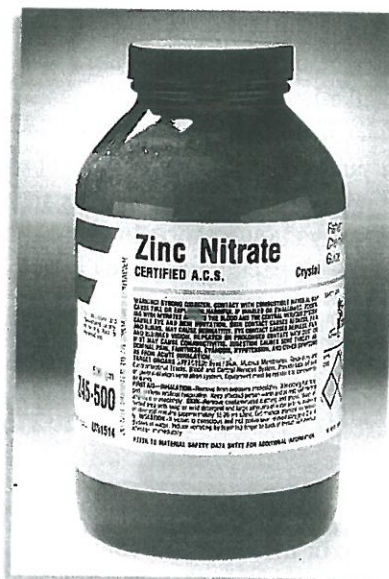
FIGURE 10 (a) Passing an electric current through water causes the compound to break down into the elements hydrogen and oxygen, which differ in composition from water. (b) When sucrose is heated, it caramelizes. When it is heated to a high enough temperature, it breaks down completely into carbon and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



(b)

TABLE 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)	



Certificate of Actual Lot Analysis

Acidity (as 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 (PO_4)	0.0002%
Sulfate (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

FIGURE 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?

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**. 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 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.

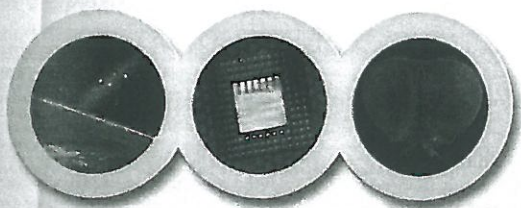
SECTION REVIEW

- 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, liquid, or 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.

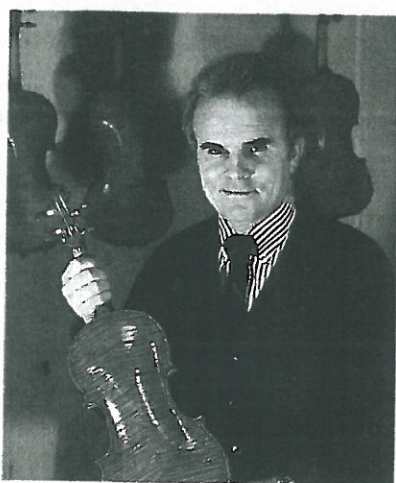


CROSS-DISCIPLINARY CONNECTION

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.

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. Attempting 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,



▲ Dr. Nagyvary and his violin

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.

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. 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?