SECTION 1

What Is Matter?

KEY TERMS
- chemistry
- matter
- element
- atom
- compound
- molecule
- chemical formula
- pure substance
- mixture

OBJECTIVES
- **Explain** the relationship between matter, atoms, and elements.
- **Distinguish** between elements and compounds.
- **Describe** molecules, and explain how they are formed.
- **Interpret** and write some common chemical formulas.
- **Categorize** materials as pure substances or mixtures.

chemistry the scientific study of the composition, structure, and properties of matter and the changes that matter undergoes

matter anything that has mass and takes up space

Making glass, as shown in ***Figure 1,*** is the process of changing the raw materials sand, limestone, and soda ash into a different substance. Such processes are what **chemistry** is all about: what things are made of, what their properties are, and how they interact and change. Chemistry is an important part of your daily life. Everything you use, from soaps to foods to carbonated drinks to books, you choose because of chemistry—what the object is made of, what its properties are, or how it changes.

Glass is used as a building material because its properties of being transparent, solid, and waterproof meet the needs we have for windows. The properties of sand, on the other hand, do not meet these needs. Chemistry helps you recognize how the differences in materials' properties relate to what the materials are composed of.

Composition of Matter

You are made of **matter.** This book is also matter. All the materials you can hold or touch are matter. Matter is anything that has mass and occupies space. The air you are breathing is matter even though you cannot see it. Light and sound are not matter. Unlike air, they have no mass or volume.

Figure 1

Glass blowers have been practicing their craft for more than 2000 years. Raw materials are changed into a new substance during the glass making process.

Atoms are matter

Wood is matter. Because it is rigid and lightweight, wood is a good choice for furniture and buildings. When wood gets hot enough, it chars—its surface turns black. The wood surface breaks down to form carbon, another kind of material that has different properties. The carbon in the charred remains will not decompose by further chemical reactions because carbon is an **element** and each element is made of only one kind of **atom.**

Diamonds, such as the one shown in ***Figure 2,*** are made of atoms of the element carbon. The shiny foil wrapped around a baked potato is made of atoms of the element aluminum. The elements that are most abundant on Earth and in the human body are shown in ***Figure 3.*** Each element is designated by a one- or two-letter symbol that is used worldwide. Symbols for elements are always a single capital letter or a capital letter followed by a lowercase letter. There are no exceptions! For example, the symbol for carbon is C, iron is Fe, copper is Cu, and aluminum is Al. Each of the more than 110 elements that we know of is unique and has different properties from the rest.

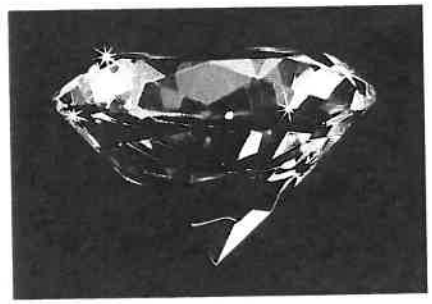


Figure 2
This diamond is made of carbon atoms.

element a substance that cannot be seperated or broken down into simpler substances by chemical means

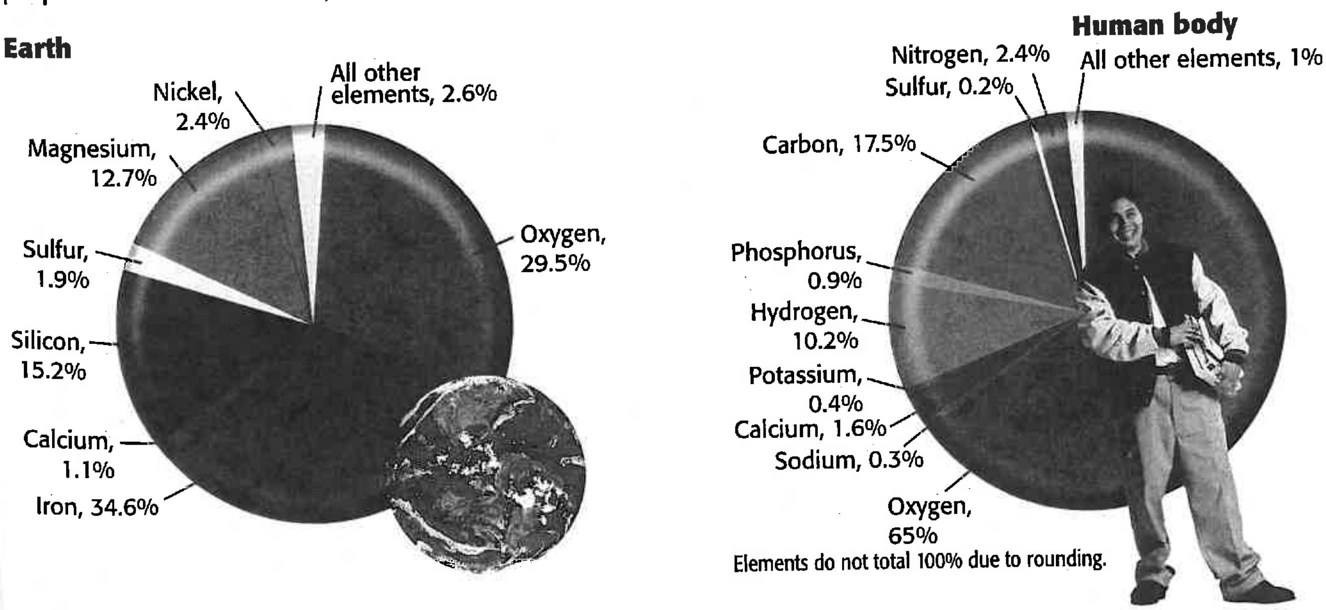
atom the smallest unit of an element that maintains the properties of that element

compound a substance made of atoms of two or more different elements that are chemically combined

Elements combine chemically to form a compound

Many familiar substances, such as aluminum and iron, are elements. Nylon is a familiar substance, but it is not an element. Nylon is a **compound.** The basic unit that makes up nylon contains carbon, hydrogen, nitrogen, and oxygen atoms, but each strand contains many of these units linked together.

Figure 3
Earth and the human body differ in the kind and proportion of elements they are composed of.



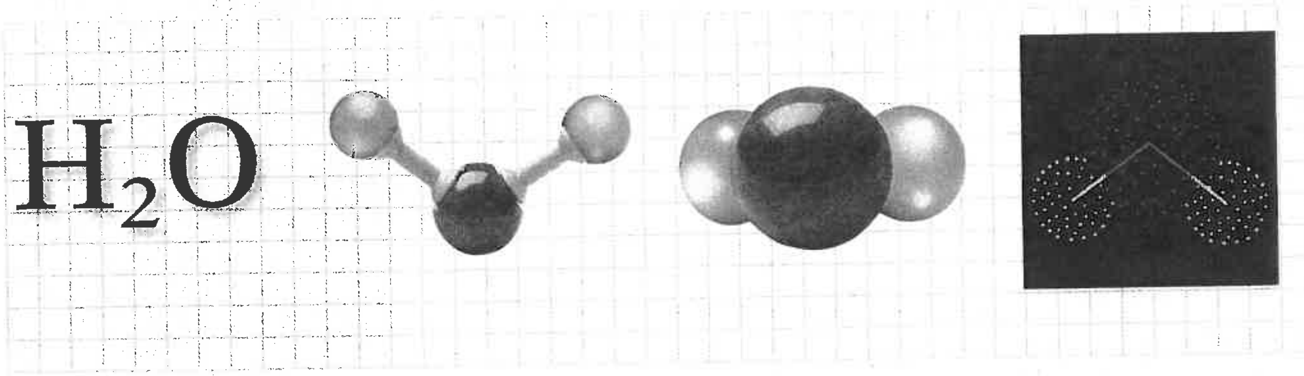


Figure 4

A water molecule can be represented by a formula, physical models, or computer images.

Compounds have unique properties

Every compound is different from the elements it contains. For example, the elements hydrogen, oxygen, and nitrogen occur in nature as colorless gases. Yet when they combine with carbon to form nylon, the strands of nylon are a flexible solid.

When elements combine to make a specific compound, the elements always combine in the same proportions. For example, iron(III) oxide, which we see often as rust, always has two atoms of iron for every three atoms of oxygen.

A molecule acts as a unit

molecule the smallest unit of a substance that keeps all of the physical and chemical properties of that substance

Atoms can join together to make millions of **molecules** like letters of the alphabet combine to form different words. A molecular substance you are familiar with is water. A water molecule is made of two hydrogen atoms and one oxygen atom, as shown in ***Figure 4.***

When oxygen and hydrogen atoms form a molecule of water, the atoms combine and act as a unit. That is what a molecule is—the smallest unit of a substance that behaves like the substance. Most molecules are made of atoms of different elements, such as water. But a molecule may also be made of atoms of the same element, such as those shown in ***Figure 5.*** A compound is made of atoms of two or more different elements, but a molecule may be of the same elements or different elements.

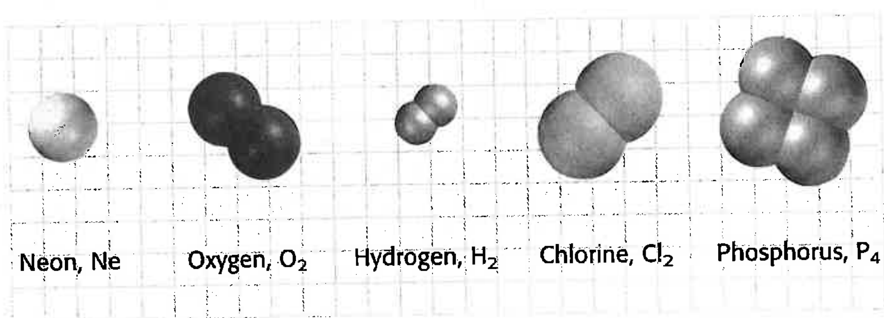


Figure 5

The atoms of elements such as neon, Ne, are found singly in nature. Other elements, such as oxygen, hydrogen, chlorine, and phosphorus, form molecules that have more than one atom. Their unit molecules are O_2, H_2, Cl_2, and P_4.

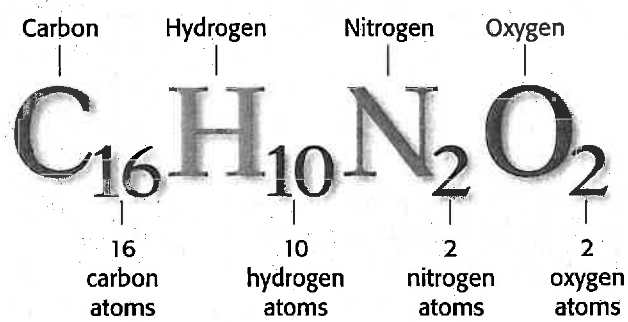
Chemical formulas represent compounds and molecules

Indigo is the dye first used to turn jeans blue. The **chemical formula** for a molecule of indigo, $C_{16}H_{10}N_2O_2$, is shown in ***Figure 6.*** A chemical formula shows how many atoms of each element are in a unit of a substance. In a chemical formula, the number of atoms of each element is written after the element's symbol as a *subscript.* If only one atom of an element is present, no subscript number is used.

Numbers placed in front of the chemical formula show the number of molecules. So, three molecules of table sugar are written as $3C_{12}H_{22}O_{11}$. Each molecule of sugar contains 12 carbon atoms, 22 hydrogen atoms, and 11 oxygen atoms.

Figure 6

The chemical formula for a molecule of indigo shows that it is made of four elements and 30 atoms.



Pure Substances and Mixtures

The word *pure* often means "not mixed with anything." For example, "pure grape juice" contains the juice of grapes and nothing else. In chemistry, the word *pure* has another meaning. A **pure substance** is matter that has a fixed composition and definite properties.

So, grape juice actually is not a pure substance. It is a **mixture** of many pure substances, such as water, sugars, and vitamins. The composition of grape juice is not fixed; it can have different amounts of water or sugar. Elements and compounds are pure substances, but mixtures are not. Many of the foods we eat are mixtures. The air we breathe is a mixture of gases.

Figure 7 shows a mixture and a pure substance. A mixture, such as grape juice, can be separated into its components. The components of water, a pure substance, are chemically combined and cannot be separated in the same way that the components of grape juice can be separated.

- **chemical formula** a combination of chemical symbols and numbers to represent a substance
- **pure substance** a sample of matter, either a single element or a single compound, that has definite chemical and physical properties
- **mixture** a combination of two or more substances that are not chemically combined

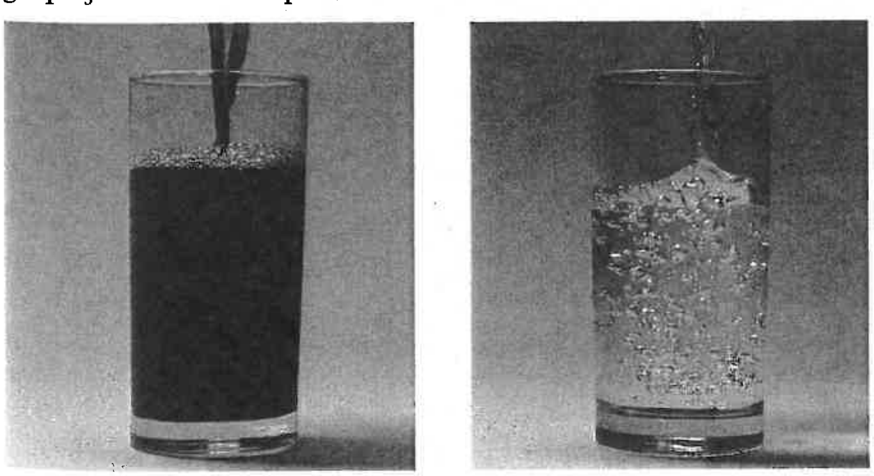
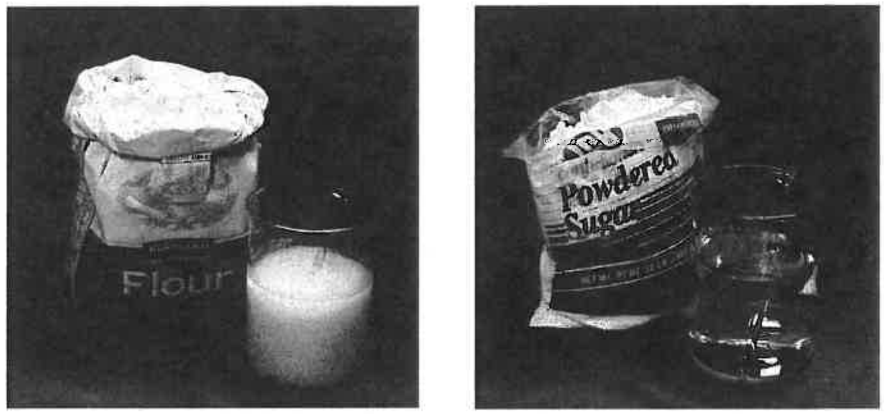


Figure 7

Grape juice is a mixture, and water is a pure substance. The components of grape juice, such as sugar and water, are not chemically combined. Water is a pure substance made up of the elements hydrogen and oxygen, which are chemically combined.

Figure 8



A Flour is suspended in water.

B Powdered sugar is dissolved in water.

Mixtures are formed by mixing pure substances

While a compound is different from the elements that it is composed of, a mixture may have properties that are similar to the pure substances that form it. Although you cannot see the different pure substances in grape juice, the mixture has chemical and physical properties in common with its components. Grape juice is a liquid like the water that it contains, and it is sweet like the sugar that it also contains.

Mixtures are classified by how thoroughly the substances mix

Some mixtures are made by putting solids and liquids together. In ***Figure 8,*** two white, powdery solids—flour and powdered sugar—are each mixed with water. Although these solids look similar, the mixtures they form with water are different.

The flour and water form a cloudy white mixture. The flour does not dissolve in water. A mixture like this is called a *heterogeneous mixture.* The substances aren't mixed uniformly and are not evenly distributed.

The sugar-water mixture looks very different from the flour-water mixture. You cannot see the sugar, and the mixture is clear. Powdered sugar dissolves in water. If you leave the mixture for a long time, the sugar will not settle out. Sugar and water form a *homogeneous mixture* because the components are evenly distributed, and the mixture is the same throughout.

Gasoline is a liquid mixture—a homogeneous mixture of at least 100 liquids. Thus, gasoline is composed of *miscible* liquids.

If you shake a mixture of oil and water, the oil and water will not mix well together, and the water will settle out. Oil and water are *immiscible.* You can see two layers in the mixture.

INTEGRATING

BIOLOGY

The pure substance indigo is a natural dye made from plants of the genus *Indigofera,* which is in the pea family. Before synthetic dyes were developed, indigo plants were widely grown in the East Indies, in India, and in the Americas. Most indigo species are shrubs 1 to 2 m tall. The leaves and branches are fermented to yield a paste, which is formed into blocks and then ground. The blue color develops when the material is exposed to air.

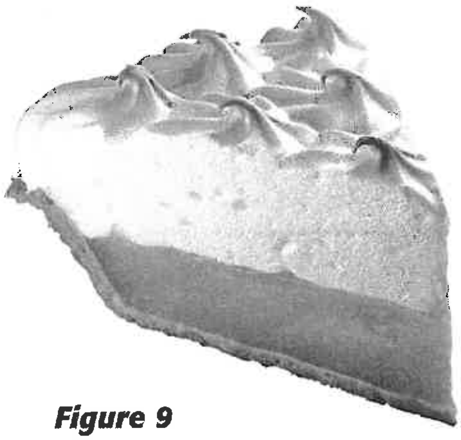


Figure 9

The meringue in this pie is a mixture of air and liquid egg white that has been beaten and then heated to form a solid foam.

Gases can mix with liquids

Air is a mixture of gases consisting mostly of nitrogen and oxygen. You inhale oxygen every time you breathe because the gases mixed in air form a homogeneous mixture. Carbonated drinks are also homogeneous mixtures. They contain sugar, flavorings, and carbon dioxide gas, CO_2, dissolved in water.

Even a liquid that is not carbonated can contain dissolved gases. For example, if you let a glass of cold water stand overnight, you may see bubbles on the sides of the glass the next morning. The bubbles form when some of the air that was dissolved in the cold water comes out of solution as the water warms up.

Carbonated drinks often have a foam on top. A foam is a kind of gas-liquid mixture. The gas is not dissolved in the liquid but has formed tiny bubbles in it. The bubbles join together to form bigger bubbles that escape from the foam, which causes the foam to collapse.

Other foams are stable and last for a long time. For example, if you whip egg whites with enough air, you get a foam. If you bake that foam in an oven, the liquid egg white dries and hardens, and you have a solid foam—meringue, shown in ***Figure 9.***

SECTION 1 REVIEW

SUMMARY

- Matter has mass and occupies space.
- An element is a substance that cannot be broken down into simpler substances.
- An atom is the smallest unit of an element that has the properties of the element.
- Atoms can combine to form molecules or compounds.
- Chemical formulas represent the atoms in compounds and molecules.
- A mixture is a combination of two or more pure substances. Mixtures can be categorized as heterogeneous or homogeneous.

1. **State** the relationship between atoms and elements. Are both atoms and elements matter?
2. **List** the two types of pure substances.
3. **Describe** matter, and explain why light is not matter. Is light made of atoms and elements?
4. **Define** *molecule*, and give examples of a molecule formed by one element and a molecule formed by two elements.
5. **Classify** each of the following as an element or a compound.
   a. sulfur, S_8
   b. methane, CH_4
   c. carbon monoxide, CO
   d. cobalt, Co
6. **State** the chemical formula of water.
7. **Compare and Contrast** mixtures and pure substances. Give an example of each.
8. **Critical Thinking** David says, "'Pure honey' means it has nothing else added." Susan says, "The honey is not really pure. It is a mixture of many substances." Who is right? Explain your answer.

SECTION 2

Properties of Matter

OBJECTIVES

- **Distinguish** between the physical and chemical properties of matter, and give examples of each.
- **Perform** calculations involving density.
- **Explain** how materials are suited for different uses based on their physical and chemical properties, and give examples.
- **Describe** characteristic properties, and give examples.

KEY TERMS

melting point
boiling point
density
reactivity
flammability

The frame and engine of a car are made of steel. Steel is a mixture of iron, other metallic elements, and carbon. It is a strong solid that provides structure. The tires are made of a flexible solid that cushions your ride. You may not think of the cars you see in ***Figure 10*** as examples of chemistry. However, the properties and changes that make steel, gasoline, and other substances useful in cars are explained by chemistry.

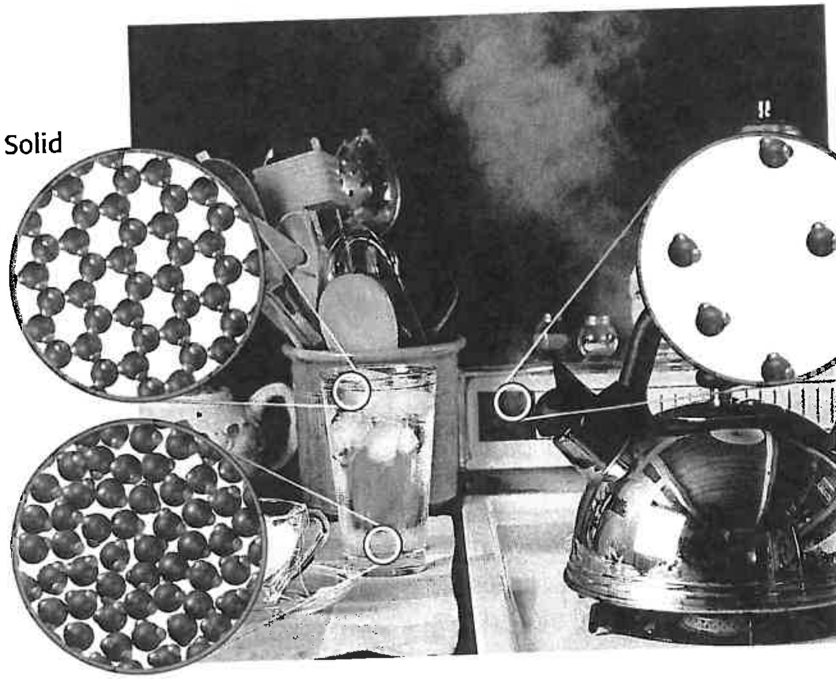
Physical Properties

Some properties of matter, such as color and shape, are called *physical properties.* Physical properties are often very easy to observe. You rely on physical properties to identify things. You recognize your friends by their physical properties, such as height and hair color. When playing sports, you choose a ball that has the shape and mass suitable for your game. Mass, volume, and density are physical properties of matter. Matter can also be described in terms of the absence of a physical property. A physical property of air is that it is colorless.

Figure 10
The physical and chemical properties of substances determine how they are used in these cars.

Figure 11

These models show 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.



Physical properties describe matter

Many physical properties can be observed or measured to help identify a substance. You can use your senses to observe some of the basic physical properties of a substance: shape, color, odor, and texture. Other physical properties, such as **melting point, boiling point,** strength, hardness, and the ability to conduct electricity, magnetism, or heat, can be measured.

melting point the temperature and pressure at which a solid becomes a liquid

boiling point the temperature at which a liquid becomes a gas

Because many physical properties remain constant for pure substances, you can use your observations or measurements of these properties to identify substances. At room temperature and atmospheric pressure, all samples of pure water are colorless and liquid; pure water is never a powdery green solid.

A characteristic of any pure substance is that its boiling point and its melting point are constant if the pressure remains the same. At sea level, water boils at 100°C and freezes at 0°C. It doesn't matter if you have a lot of water or a little water; these physical properties of the water are the same regardless of the mass or volume involved. This statement is true for all pure substances.

An easily observed physical property is *state*—the physical form in which a substance exists. Solids, liquids, and gases are three common states of matter. ***Figure 11*** shows the solid, liquid, and gas states of water at the molecular level.

Density is a physical property

Density is a measurement of how much matter is contained in a certain volume of a substance. A substance that has a low **density** is "light" in comparison with something else of the same volume. The balloons in ***Figure 12*** float because they are less dense than the air around them. A substance that has a high density is "heavy" in comparison with another object of the same volume. A stone sinks to the bottom of a pond because the stone is more dense than the water around it.

You can compare the density of two objects of the same volume by holding one in each hand. The lighter one is less dense; the heavier one is more dense. If you held a brick in one hand and an equal-sized piece of sponge in the other hand, you would know instantly that the brick is more dense than the sponge. Remember that weight and density are different. Two pounds of feathers are heavier than one pound of steel. But the feathers are less dense than the steel, so two pounds of feathers have a greater volume than one pound of steel.

Density determines whether an object will float or sink. An object will float when placed in water if it is less dense than water. If an object is more dense than water, the object will sink. ***Table 1*** lists the densities of some common substances. The density of an object is calculated by dividing the object's mass by its volume.

Figure 12

Helium-filled balloons float upward because helium is less dense than air is. Similarly, hot-air balloons rise because hot air is less dense than cool air is.

density the ratio of the mass of a substance to the volume of a substance

Density Equation

$$D = m/V$$

$$\textit{density} = \textit{mass/volume}$$

Table 1 **Densities of Some Substances**

Substance	Chemical formula	Density in g/cm^3
Air, dry	mixture	0.00129
Brick, common	mixture	1.9
Gasoline	mixture	0.7
Helium	He	0.00018
Ice	H_2O	0.92
Iron	Fe	7.86
Lead	Pb	11.3
Nitrogen	N_2	0.00125
Steel	mixture	7.8
Water	H_2O	1.00

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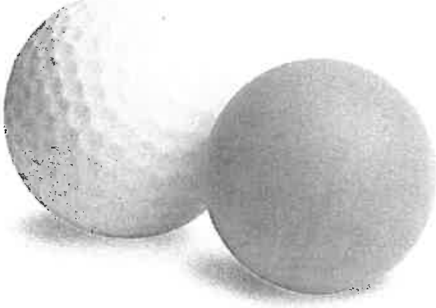


Figure 13

A golf ball is denser than a table-tennis ball because the golf ball contains more matter in about the same volume.

Density is often measured in units of g/cm^3

A golf ball and a table tennis ball are shown in ***Figure 13.*** Which ball is more dense? The two balls have a similar volume, but the mass of a golf ball is 45.9 g and the mass of a table tennis ball is 2.5 g. The golf ball has more mass per unit of volume than a table tennis ball has, and therefore the golf ball is more dense.

The density of a liquid or a solid is usually reported in units of grams per cubic centimeter (g/cm^3). For example, 10.0 cm^3 of water has a mass of 10.0 g. Its density is 10.0 g for every 10.0 cm^3, or 1.00 g/cm^3. A cubic centimeter contains the same volume as a milliliter. You may see the density of water expressed as 1 g/mL.

Practice HINT

- When a problem requires you to calculate density, you can use the density equation. $D = \frac{m}{V}$
- You can solve for mass by multiplying both sides of the density equation by volume. $DV = \frac{mV}{V}$ $\quad m = DV$
- You will need to use this form of the equation in Practice Problem 3.
- You can solve for volume by dividing both sides of the equation shown above by density. $\frac{m}{D} = \frac{DV}{D}$ $\quad V = \frac{m}{D}$

Math Skills

Density If 10.0 cm^3 of ice has a mass of 9.17 g, what is the density of ice?

1 List the given and the unknown values.

Given: *mass,* $m = 9.17$ g

volume, $V = 10.0$ cm^3

Unknown: *density,* $D = ?$ g/cm^3

2 Write the equation for density.

$D = \frac{m}{V}$ **or** *density = mass/volume*

3 Insert the known values into the equation, and solve.

$D = 9.17 \text{ g}/10.0 \text{ cm}^3$

$D = 0.917 \text{ g/cm}^3$

Practice

Density

1. A piece of tin has a mass of 16.52 g and a volume of 2.26 cm^3. What is the density of tin?
2. A man has a 50.0 cm^3 bottle completely filled with 163 g of a slimy green liquid. What is the density of the liquid?
3. A piece of metal has a density of 11.3 g/cm^3 and a volume of 6.7 cm^3. What is the mass of this piece of metal?

Physical properties help determine uses

Every day, you use physical properties to identify substances. Physical properties help you determine whether your socks are clean (odor), whether you can fit all your books into your backpack (volume), or whether your shirt matches your pants (color).

In industry, physical properties are used to select substances that may be useful. Copper is used in electrical power lines, telephone lines, and electric motors because it conducts electricity well. Antifreeze, which contains ethylene glycol (a poisonous liquid), remains a liquid at temperatures that would freeze or boil water in a car radiator. As shown in ***Figure 14,*** aluminum is used in foil because it is lightweight yet durable, water resistant, and flexible.

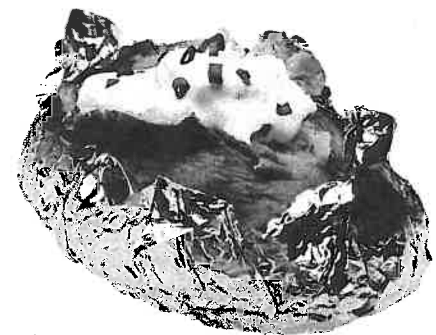


Figure 14
Aluminum is light, strong, and durable, which makes it ideal for use in foil.

Can you think of other physical properties that help us determine how we can use a substance? Some substances have the ability to conduct heat, while others do not. Plastic-foam cups do not conduct heat well, so they are often used for holding hot drinks. What would happen if you poured hot tea into a metal cup?

Quick Lab

How are the mass and volume of a substance related?

Materials
- *100 mL graduated cylinder*
- *250 mL beaker with 200 mL water*
- *balance*
- *graph paper*

1. Make a data table that has 3 columns and 12 rows. In the first row, label the columns "Volume of H_2O (mL)," "Mass of cylinder (g) and H_2O (g)," and "Mass of H_2O (g)." In the remaining spaces of the first column, write 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100.
2. Measure the mass of the empty graduated cylinder, and record it on a piece of paper.
3. For each amount of water listed in column one, pour the water from the beaker into the graduated cylinder. Then, use the balance to find the mass of the graduated cylinder with the water. Record each value in column two of your data table.
4. On graph paper, make a graph and label the horizontal *x*-axis "Mass of water (g)." Mark the *x*-axis in 10 equal increments for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 g. Label the vertical *y*-axis "Volume of water (mL)." Mark the *y*-axis in 10 equal increments for 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 mL.
5. Plot a graph of your data either on graph paper, on a graphing calculator, or by using a graphing/spreadsheet computer program.

COMPUTER SKILL

Analysis

1. What is the mass of the graduated cylinder?
2. Use your graph to estimate the mass of 55 mL of water and 100 mL of water.
3. Use your graph to predict the volume of 25 g of water and 75 g of water.
4. How could you use your data table or graph to calculate the density of water? Which method do you think gives better results? Why?

Chemical Properties

Some elements, such as sodium, react very easily with other elements and usually are found as compounds in nature. Other elements, like gold, are much less reactive and often are found uncombined in nature. Magnesium is so reactive that it is used to make emergency flares. Light bulbs are filled with argon gas because argon is not reactive, so the tungsten filament lasts longer. All of these are examples of *chemical properties*. Chemical properties are generally not as easy to observe as physical properties.

reactivity the ability of a substance to combine chemically with another substance

flammability the ability of a substance to react in the presence of oxygen and burn when exposed to a flame

Chemical properties describe how a substance reacts

Although iron has many useful physical and chemical properties, one property that can cause problems for people is its reactivity with oxygen. When iron is exposed to oxygen, it rusts. You can see rust on the old car shown in ***Figure 15.*** The steel parts of a car rust when iron atoms in the steel react with oxygen in air to form iron(III) oxide. The painted and chromium parts of the car do not rust because they does not react with oxygen.

Chemical properties are related to the specific elements that make up substances. The elements in steel, paint, and chrome have different chemical properties. A chemical property describes how a substance changes into a new substance, either by combining with other elements or by breaking apart into new substances. Chemical properties include the **reactivity** of elements or compounds with oxygen, acid, water, or other substances.

Another chemical property is **flammability**—the ability to burn. For example, wood can be burned to create new substances (ash and smoke) with properties that are different from the original wood. A substance that does not burn, such as gold, has the chemical property of nonflammability. Remember that even when wood is not actually burning, it is still flammable because flammability is one of wood's chemical properties. A substance always has its chemical properties, even when you cannot observe them.

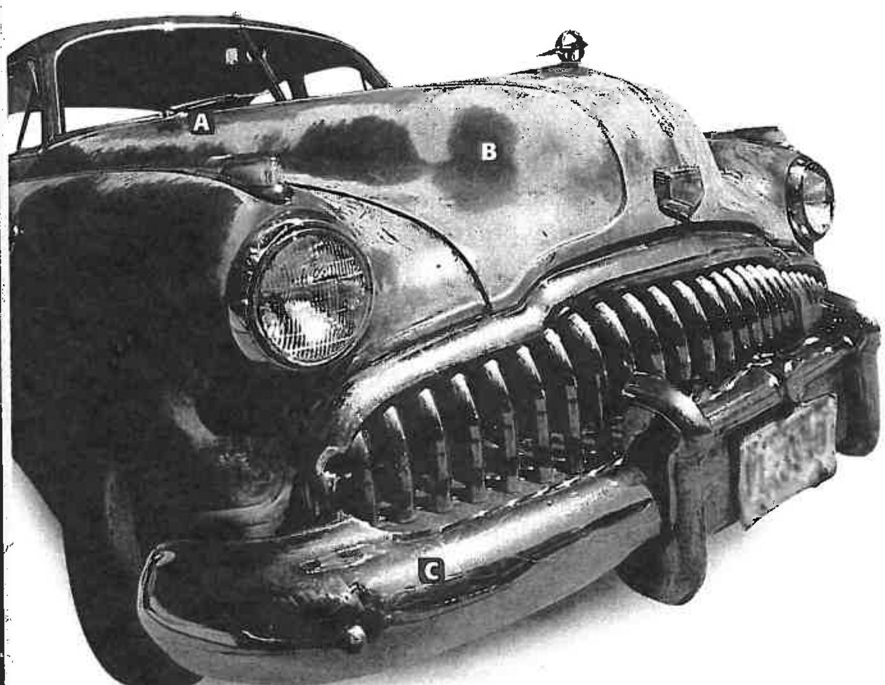


Figure 15

A This hole started as a small chip in the paint, which exposed the iron in the car to oxygen. The iron rusted and crumbled away.

B Paint does not react with oxygen, so it provides a barrier between oxygen and the iron in the car's steel.

C This bumper is rust free because it is coated with chromium, which is nonreactive with oxygen.

Comparing Physical and Chemical Properties

It is important to remember the differences between physical and chemical properties. You can observe physical properties without changing the identity of the substance. But you can observe chemical properties only in situations in which the identity of the substance changes.

Table 2 summarizes the physical and chemical properties of some common substances. As you can see, many substances have very similar physical properties but completely different chemical properties. For example, baking soda and powdered sugar are both white powders, but baking soda reacts with vinegar, whereas sugar does not.

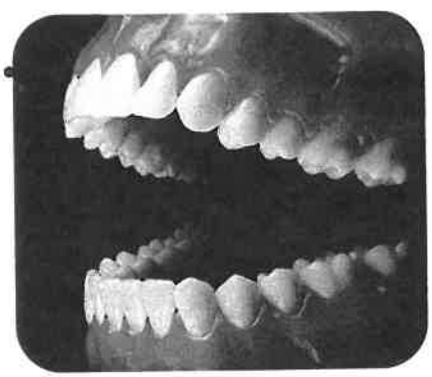
Did You Know?

Galvanized steel is steel that is coated with zinc to prevent rusting. It is used in buckets and nails. Steel coated with tin is used in food cans and containers. Today, most canned carbonated beverages are packaged in aluminum cans instead of steel cans.

Table 2 **Comparing Physical and Chemical Properties**

Substance	Physical property	Chemical property
Helium	less dense than air	nonflammable
Wood	grainy texture	flammable
Baking soda	white powder	reacts with vinegar to produce bubbles
Powdered sugar	white powder	does not react with vinegar
Rubbing alcohol	clear liquid	flammable
Red food coloring	red color	reacts with bleach and loses color
Iron	malleable	reacts with oxygen

REAL WORLD APPLICATIONS



Choosing Materials Materials are chosen because their properties are suitable for use. For example, white acrylic plastic can be used to make false teeth. Sometimes, porcelain is used. Metals are less commonly used, although gold teeth are still made sometimes. False teeth have a demanding job to do. They are constantly bathed in saliva, which is corrosive. They must withstand the forces from chewing hard objects, such as popcorn or hard candy. The material chosen has to be nontoxic, hard, waterproof, unreactive, toothlike in appearance, and affordable. Acrylic plastic satisfies these requirements.

George Washington wore false teeth, which were common in the 1700s. But contrary to the legend that his teeth were wood, they were made of hippopotamus bone.

Applying Information

1. Compare the advantages and disadvantages of gold false teeth and Washington's bone teeth.
2. Identify some advantages of acrylic plastic teeth.

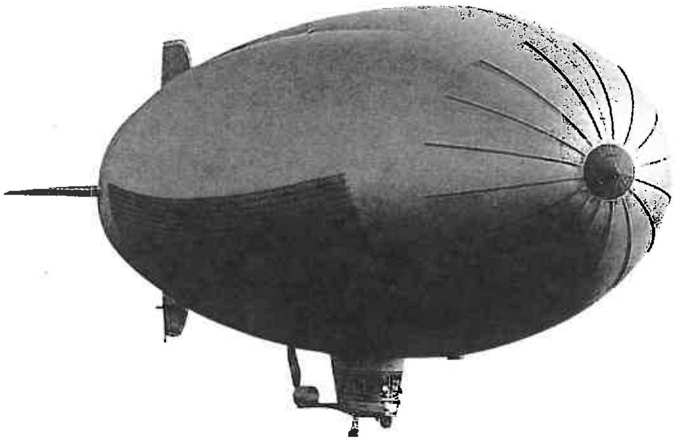


Figure 16
Helium is used in blimps because it is less dense than air and is nonflammable.

Characteristic properties help to identify and classify substances

You can describe matter by both physical and chemical properties. The properties that are most useful in identifying a substance, such as density, solubility (whether or not it dissolves), and reactivity with acids, are its *characteristic properties.* Characteristic properties include both types—physical and chemical properties. The characteristic properties of a substance are always the same whether the sample you are observing is large or small.

The blimp in ***Figure 16*** is filled with helium. The characteristic properties of helium, such as its density and nonflammability, make helium very useful for blimp flight.

SECTION 2 REVIEW

SUMMARY

- Physical properties can be observed or measured without changing the composition of matter.
- Physical properties help determine how substances are used.
- The density of a substance is equal to its mass divided by its volume.
- Chemical properties describe how a substance reacts; they can be observed when one substance reacts with another.
- Scientists use characteristic properties to identify and classify substances.

1. **Classify** the following as either chemical or physical properties.
   a. is shiny and silvery
   b. melts easily
   c. has a density of 2.3 g/cm^3
   d. tarnishes in moist air
2. **Identify** which of the following properties *are not* chemical properties.
   a. reacts with water
   b. boils at 100°C
   c. is red
   d. does not react with hydrogen
3. **Describe** several uses for plastic, and explain why plastic is a good choice for these purposes.
4. **Describe** characteristic properties, and explain why they are important. List some characteristic properties.

Math Skills

5. **Calculate** the density of a rock that has a mass of 454 g and a volume of 100 cm^3.
6. **Calculate** the density of a substance in a sealed 2500 cm^3 flask that is full to capacity with 0.36 g of a substance.
7. **Critical Thinking** Suppose you need to build a raft. Write a paragraph describing the physical and chemical properties of the raft that would be important to ensure your safety.

SECTION 3

Changes of Matter

OBJECTIVES

- **Explain** physical change, and give examples of physical changes.
- **Explain** chemical change, and give examples of chemical changes.
- **Compare and contrast** physical and chemical changes.
- **Describe** how to detect whether a chemical change has occurred.

KEY TERMS

physical change
chemical change

Some materials benefit us because they stay in the same state and do not change under normal conditions. Surgical steel pins are used to reinforce broken bones because surgical steel remains the same even after years in the human body. Concrete and glass are used as building materials because they change very little under most weather conditions. Other materials are valued for their ability to change states easily. Water is turned into steam to heat homes and factories. Liquid gasoline is changed into a gas so it can burn in car engines. The physical and chemical properties of a substance determine how the substances behave under different conditions.

physical change a change of matter from one form to another without a change in chemical properties

Physical Changes

A **physical change** affects one or more physical properties of a substance without changing its identity. For example, if you break a piece of chalk in two, you change its physical properties of size and shape. But no matter how many times you break it, chalk would still be chalk and the chemical properties of the chalk would remain unchanged. Each piece of chalk would still produce bubbles if you placed it in vinegar.

Figure 17 shows a physical change taking place. The girl in the picture is getting her hair cut, but the chemical nature of her hair is not changing. The haircut will affect only the physical properties of her hair. Other examples of physical changes are dissolving sugar, melting ice, sanding a piece of wood, crushing an aluminum can, and mixing oil and vinegar.

Figure 17
Is this haircut a physical or a chemical change?

Physical changes do not change a substance's identity

Both quartz crystals and sand are made of SiO_2, but they look different. When quartz is crushed into sand, a physical change takes place. During physical changes, energy is absorbed or released. After a physical change, a substance may look different, but the arrangement of atoms that make up the substance are not changed.

Pounding a gold nugget into a ring results in physical changes. But physical changes do not change all the properties of a substance. For example, the color of the gold, its melting point, and its density do not change. Melting, freezing, and evaporating—all changes of state—are physical changes, too, because the identity of the substance does not change.

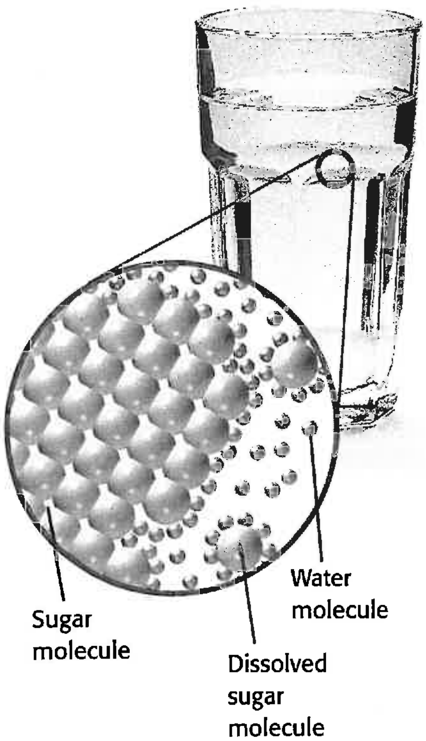


Figure 18

When sugar dissolves in water, water particles attract and pull apart sugar particles, so the sugar particles spread out in the water.

Dissolving is a physical change

When you stir sugar into water, the sugar dissolves and seems to disappear. But the sugar is still there; you can taste the sweetness when you drink the water. ***Figure 18*** shows sugar and water molecules dissolving. When sugar dissolves, it seems to disappear because the sugar particles become spread out between the particles of the water. The molecules of the sugar have not changed because dissolving is a physical change. Dissolving a solid in a liquid, a gas in a liquid, or a liquid in a liquid are all physical changes.

Quick Lab

How can physical properties separate a mixture?

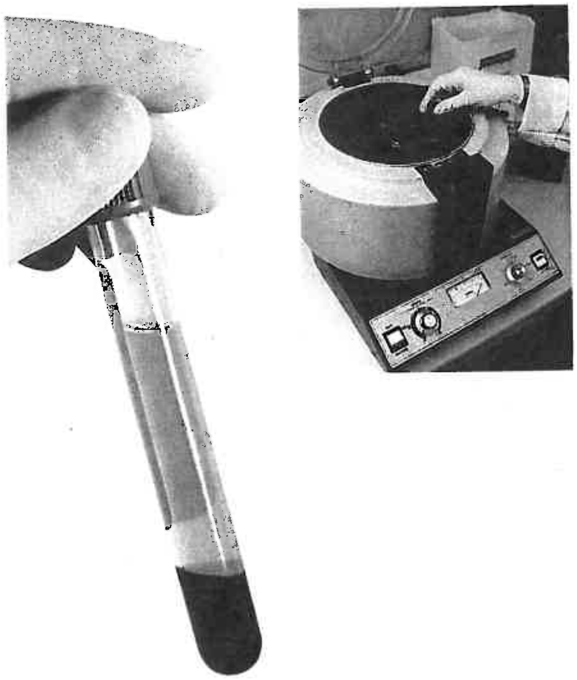
Materials
- *distilled water*
- *clear plastic cups*
- *filter funnel*
- *plastic spoon*
- *filter paper*
- *5 g sample of mixture*
- *magnet*
- *paper towels*

1. Design an experiment in which the given materials are used to separate the components of the sample mixture. (**Hint:** Consider physical properties such as solubility, density, and magnetism.)
2. Once you have separated the components of the sample mixture, describe them by their physical properties.

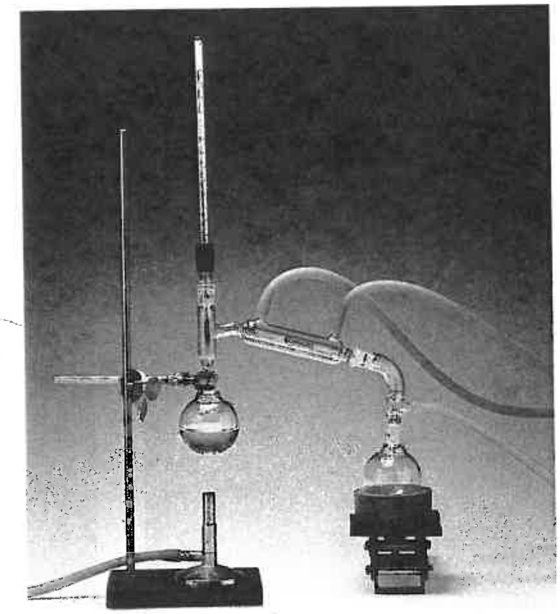
Analysis

1. What properties did you observe in each of the components of the mixture?
2. How did these properties help you to separate the components of the sample?
3. Did any of the components share similar properties?
4. Based on your observations, what do you think the mixture was composed of?

Figure 19
These pictures show ways that physical changes can be used to separate mixtures.



A A centrifuge is a tool used to separate mixtures. It spins a sample of a mixture rapidly until the components of the mixture separate. You can see different layers in this sample of blood because it has been separated into its components.



B The distillation device shown here can separate components of mixtures that have different boiling points. When heated, the component that boils and evaporates first, separates from the mixture and collects in the receiving flask.

Mixtures can be physically separated

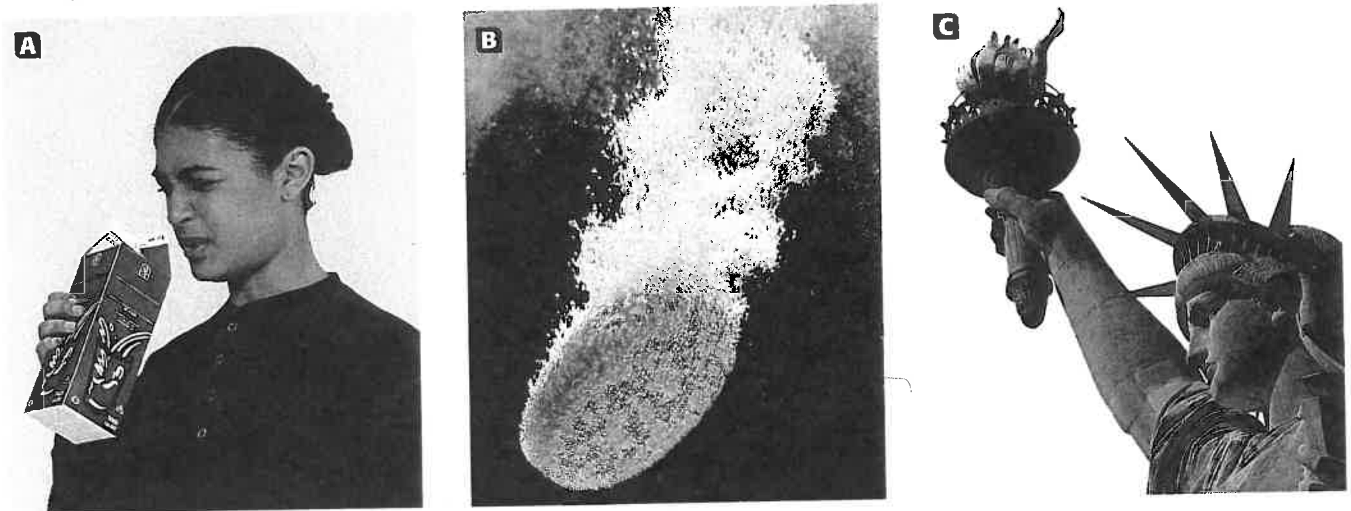
Because mixtures are not chemically combined, each component of a mixture has the same chemical makeup it had before the mixture was formed. Each substance in a mixture keeps its identity. In some mixtures, such as a slice of pizza, you can easily see the individual components. In other mixtures, such as salt water, you cannot see all the components.

You can remove the mushrooms on a pizza, which results in a physical change. The identities of the substances in the pizza would not change. Unlike mixtures, compounds can be broken down only through chemical changes.

Not all mixtures are as easy to separate as a pizza. You cannot pick salt out of a saltwater mixture, but you can separate the salt from the water by heating the mixture. When the water evaporates, the salt remains behind. Several common techniques for separating mixtures are shown in ***Figure 19.***

C Magnets can be used to separate mixtures that have components containing iron. In this mixture of nails, the magnet attracts and separates the nails containing iron from the nails that do not contain iron.

Figure 20
Examples of Chemical Changes



A Soured milk smells bad because bacteria have formed new substances in the milk.

B Effervescent tablets bubble when the citric acid and baking soda in them react with water to produce CO_2.

C The Statue of Liberty is made of shiny, orange-brown copper. But the metal's interaction with carbon dioxide and water has formed a new substance, copper carbonate.

Chemical Changes

Some materials are useful because of their ability to change and combine to form new substances. For example, the compounds in gasoline burn in the presence of oxygen to form carbon dioxide and water, which releases energy. This is a **chemical change.** A chemical change occurs when one or more substances are changed into entirely new substances that have different properties.

chemical change a change that occurs when a substance changes composition by forming one or more new substances

Chemical changes happen everywhere

You see chemical changes happening more often than you may think. When a battery "dies," the chemicals inside the battery have changed, so the battery can no longer supply energy. The oxygen you inhale is used in a series of chemical reactions in your body. After it has undergone a chemical change by reacting with carbon, the oxygen is then exhaled as part of the compound carbon dioxide. Chemical changes occur when fruits and vegetables ripen and when the food you eat is digested. ***Figure 20*** shows some examples of other chemical changes that may be familiar to you.

internet connect

www.scilinks.org
Topic: Chemical Changes
SciLinks code: HK4020

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Chemical changes form new substances that have different properties

A fun (and tasty) way to observe a chemical change is to bake a cake. When you bake a cake, you combine eggs, flour, sugar, butter, milk, baking powder, and other ingredients. Each ingredient has its own set of properties. For example, when baking powder combines with a liquid such as milk or water, it releases carbon dioxide, which causes the cake to rise. When you mix all of the ingredients and add heat by baking the cake batter, you get something completely different. The heat of the oven and the interaction of the ingredients cause chemical changes, which results in a cake with properties that are completely different from the properties of the original ingredients.

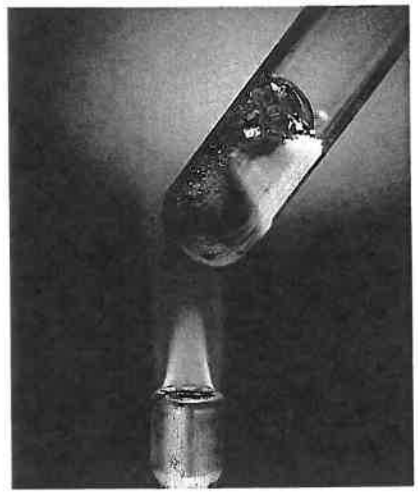

Figure 21

Table sugar is a compound made of carbon, hydrogen, and oxygen. When table sugar is heated, it caramelizes. When heated to a high temperature, it breaks down completely into carbon and water.

Chemical changes can be detected

When a chemical change takes place, there are often clues that suggest that a chemical change has happened. A change in odor or color is a good clue that a substance is changing chemically. When food burns, you can often smell the gases given off by the chemical changes. When paint fades, you can observe the effects of chemical changes in the paint. Chemical changes often cause color changes, fizzing or foaming, or the production of sound, heat, light, or odor.

Figure 21 shows table sugar being heated in a test tube. When sugar is heated to a high temperature, it breaks down into carbon and water. How do you know a chemical change is taking place in ***Figure 21***? The sugar has changed color, bubbles are forming, and a caramel smell is filling the air.

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www.scilinks.org
Topic: Physical/Chemical Changes
SciLinks code: HK4104

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Chemicals changes cannot be reversed by physical changes

Because new substances are formed in a chemical change, you cannot reverse chemical changes by using physical changes. You cannot "unbake" a cake by separating out each ingredient. Most of the chemical changes you observe in your daily life, such as a cake baking, milk turning sour, or iron rusting, are impossible to reverse. Imagine trying to unbake a cake! While some physical changes can be easily undone, chemical changes are often more difficult to undo.

However, some chemical changes can be reversed under the right conditions by other chemical changes. For example, the water formed in a space shuttle's rockets can be split back into the starting materials—hydrogen and oxygen—by using an electric current to initiate a reaction that separates the hydrogen and oxygen atoms in the water molecules.

Quick ACTIVITY

Compound Confusion

1. Measure 4 g each of compounds A and B; place each in a clear plastic cup.
2. Observe the color and texture of each compound. Record your observations.
3. Add 5 mL of vinegar to each cup. Record your observations.
4. Baking soda reacts with vinegar, but powdered sugar does not. Which of these two substances is compound A, and which is B?

Compounds can be broken down through chemical changes

Some compounds can be broken down into elements through chemical changes. When the compound mercury(II) oxide is heated, it breaks down into the elements mercury and oxygen. If an electric current is passed through melted table salt, the elements sodium and chlorine are produced.

Other compounds undergo chemical changes to form simpler compounds. Carbonic acid is a compound that gives carbonated soda a tart taste and adds "fizz." In an unopened bottle of soda, you don't see bubbles because carbon dioxide is present in the form of carbonic acid. When you open a bottle of soda, the carbonic acid breaks down into carbon dioxide and water. The carbon dioxide escapes as bubbles. Through additional chemical changes, the carbon dioxide and water can be further broken down into the elements carbon, oxygen, and hydrogen.

SECTION 3 REVIEW

SUMMARY

- Physical changes are changes in the physical properties of a substance that do not change the identity of the substance.
- Changes of state are physical changes.
- Dissolving is a physical change.
- Physical changes are often easily reversed.
- Chemical changes form new substances that have new properties. Chemical changes can be reversed only through chemical reactions.
- Chemical changes often cause changes in color or produce sound, light, odor, or heat.

1. **Classify** the following as a chemical or a physical change.
   - **a.** adding sugar to lemonade
   - **b.** plants using CO_2 and H_2O to form O_2 and sugar
   - **c.** boiling water
   - **d.** frying an egg
   - **e.** rust forming on metal
   - **f.** fruit rotting
   - **g.** removing salt from water by evaporation
2. **Explain** why changes of state are physical changes.
3. **Describe** how you would separate the components of a mixture, and state whether your methods would be physical or chemical changes.
4. **Define** physical change and chemical change, and give examples of each.
5. **Explain** why physical changes can easily be reversed but chemical changes cannot.
6. **Identify** two ways to break down a compound into simpler substances.
7. **List** three clues that indicate a chemical change.
8. **Critical Thinking** Describe the difference between physical and chemical changes in terms of what happens to the particles.