CHAPTER 3

Elements and Compounds

Flower varieties are often classified by color in the nursery.

Chapter Outline

In Chapter 1 we learned that matter can be divided into the broad categories of pure substances and mixtures. We further learned that pure substances are either elements or compounds. The chemical elements are very important to us in our daily lives. In tiny amounts they play a large role in our health and metabolism. Metallic elements are used for the skin of airplanes, buildings, and sculpture. In this chapter we explore the nature of the chemical elements and begin to learn how chemists classify them.

3.1 Elements

element

All words in English are formed from an alphabet consisting of only 26 letters. All known substances on Earth—and most probably in the universe, too—are formed from a sort of "chemical alphabet" consisting of over 100 known elements. An **element** is a fundamental or elementary substance that cannot be broken down by chemical means to simpler substances. Elements are the building blocks of all substances. The elements are numbered in order of increasing complexity beginning with hydrogen, number 1. Of the first 92 elements, 88 are known to occur in nature. The other four—technetium (43), promethium (61), astatine (85), and francium (87)—either do not occur in nature or have only transitory existences during radioactive decay. With the exception of number 94, plutonium, elements above number 92 are not known to occur naturally but have been synthesized, usually in very small quantities, in laboratories. The discovery of trace amounts of element 94 (plutonium) in nature has been reported. No elements other than those on Earth have been detected on other bodies in the universe.

See the periodic table on the inside front cover.

Most substances can be decomposed into two or more simpler substances. Water can be decomposed into hydrogen and oxygen. Sugar can be decomposed into carbon, hydrogen, and oxygen. Table salt is easily decomposed into sodium and chlorine. An element, however, cannot be decomposed into simpler substances by ordinary chemical changes.

If we could take a small piece of an element, say copper, and divide it and subdivide it into smaller and smaller particles, we would finally come to a single unit of copper that we could no longer divide and still have copper (see Figure 3.1).

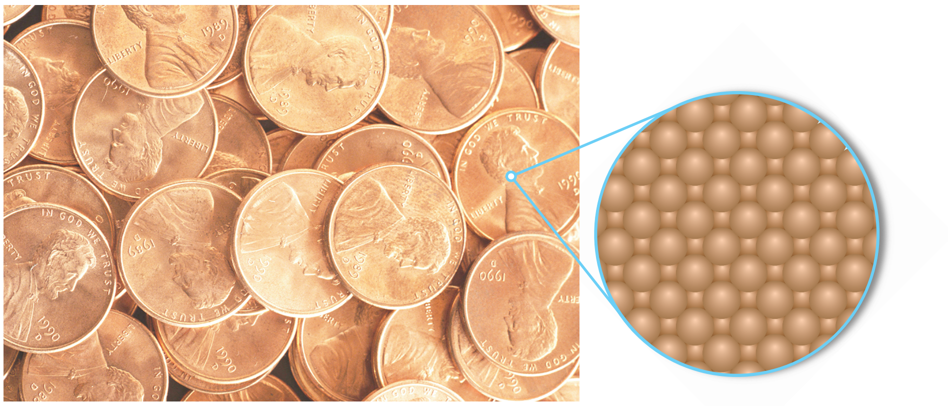


Figure 3.1
The surface of a penny is made up of tiny identical copper atoms packed tightly together.

atom

This smallest particle of an element that can exist is called an **atom**, which is also the smallest unit of an element that can enter into a chemical reaction. Atoms are made up of still smaller subatomic particles. However, these subatomic particles (described in Chapter 5) do not have the properties of elements.

3.2 Distribution of Elements

Elements are distributed unequally in nature, as shown in Figure 3.2. At normal room temperature two of the elements, bromine and mercury, are liquids. Eleven elements—hydrogen, nitrogen, oxygen, fluorine, chlorine, helium, neon, argon, krypton, xenon, and radon—are gases. All the other elements are solids.

Ten elements make up about 99% of the mass of the Earth's crust, seawater, and atmosphere. Oxygen, the most abundant of these, constitutes about 50% of this mass. The distribution of the elements shown in Figure 3.2 includes the Earth's crust to a depth of about 10 miles, the oceans, fresh water, and the atmosphere but does not include the mantle and core of the Earth, which are believed to consist of metallic iron and nickel. Because the atmosphere contains relatively little matter, its inclusion has almost no effect on the distribution. But the inclusion of fresh and salt water does have an appreciable effect since water contains about 11.2% hydrogen. Nearly all of the 0.9% hydrogen shown in the second graph in Figure 3.2 is from water.

The average distribution of the elements in the human body is shown in Figure 3.2c. Note again the high percentage of oxygen.

3.3 Names of the Elements

The names of the elements come to us from various sources. Many are derived from early Greek, Latin, or German words that describe some property of the element. For example, iodine is taken from the Greek word *iodes,* meaning

(a) (b)

(a) Bromine (Br_2) and (b) mercury (Hg) are elements that are liquid at room temperature.

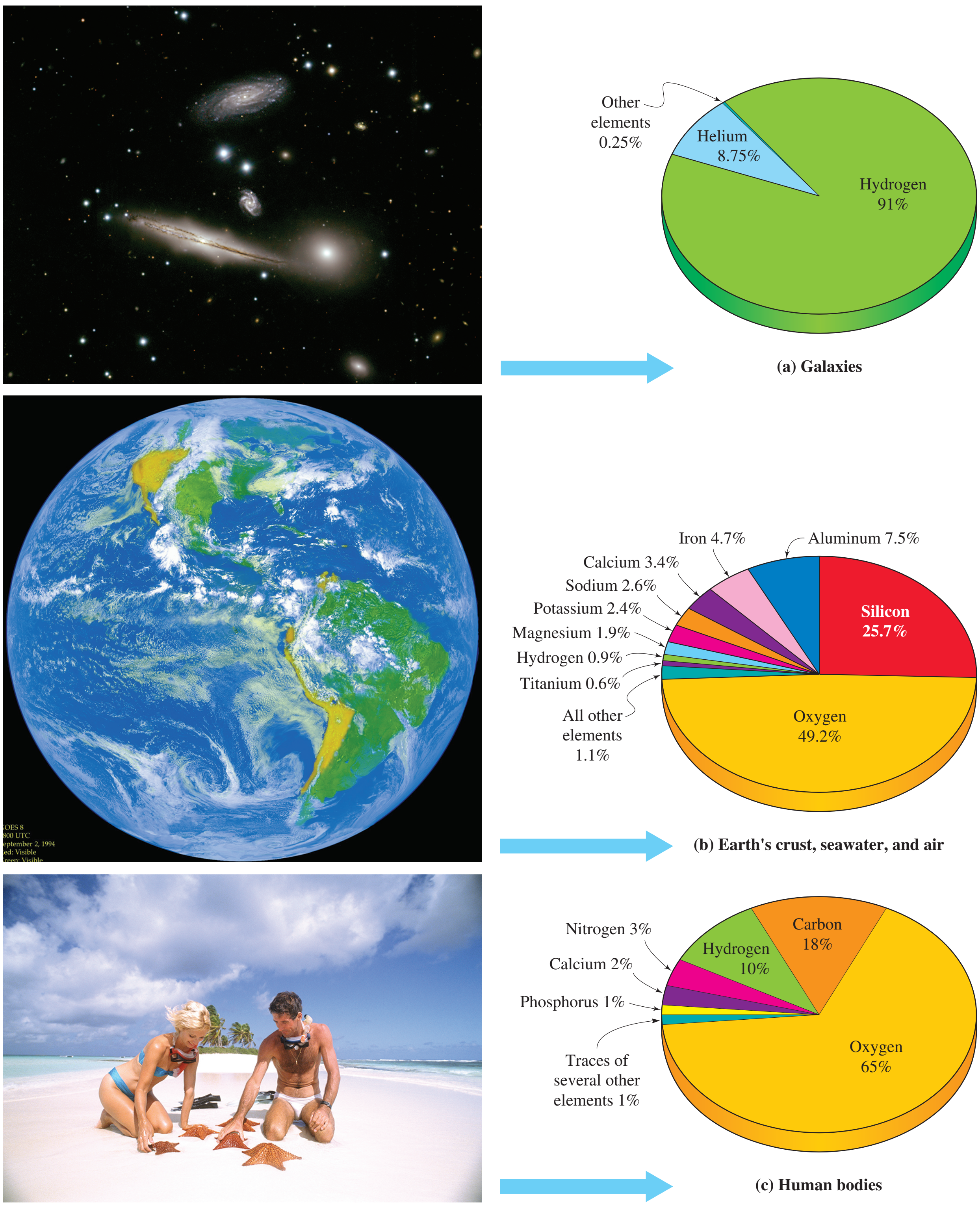


Figure 3.2
Distribution of the common elements in nature.

"violetlike," and iodine is certainly violet in the vapor state. The name of the metal bismuth originates from the German words *weisse masse,* which means "white mass." Miners called it *wismat*; it was later changed to *bismat,* and finally to bismuth. Some elements are named for the location of their discovery—for example, germanium, discovered in 1886 by a German chemist. Others are named in commemoration of famous scientists, such as einsteinium and curium, named for Albert Einstein and Marie Curie, respectively.

3.4 Symbols of the Elements

We all recognize Mr., N.Y., and Ave. as abbreviations for mister, New York, and avenue. In a like manner, each element also has an abbreviation; these are called **symbols** of the elements. Fourteen elements have a single letter as their symbol, and the rest have two letters. A symbol stands for the element itself, for one atom of the element, and (as we shall see later) for a particular quantity of the element.

symbol

Rules governing symbols of elements are as follows:

1. Symbols have either one or two letters.
2. If one letter is used, it is capitalized.
3. If two letters are used, only the first is capitalized.

Examples: Iodine I Barium Ba

The symbols and names of all the elements are given in the table on the inside front cover of this book. Table 3.1 lists the more commonly used elements and their symbols. Examine Table 3.1 carefully and you will note that most of

Iodine in its elemental form is a bluish-black crystal. The symbol for iodine is I.

The metal sodium is soft enough to cut with a knife. The symbol for sodium is Na.

Table 3.1 Symbols of the Most Common Elements

Element	Symbol	Element	Symbol	Element	Symbol
Aluminum	Al	Gold	Au	Platinum	Pt
Antimony	Sb	Helium	He	Plutonium	Pu
Argon	Ar	Hydrogen	H	Potassium	K
Arsenic	As	Iodine	I	Radium	Ra
Barium	Ba	Iron	Fe	Silicon	Si
Bismuth	Bi	Lead	Pb	Silver	Ag
Boron	B	Lithium	Li	Sodium	Na
Bromine	Br	Magnesium	Mg	Strontium	Sr
Cadmium	Cd	Manganese	Mn	Sulfur	S
Calcium	Ca	Mercury	Hg	Tin	Sn
Carbon	C	Neon	Ne	Titanium	Ti
Chlorine	Cl	Nickel	Ni	Tungsten	W
Chromium	Cr	Nitrogen	N	Uranium	U
Cobalt	Co	Oxygen	O	Xenon	Xe
Copper	Cu	Palladium	Pd	Zinc	Zn
Fluorine	F	Phosphorus	P		

The colors of these varieties of quartz are the result of the presence of different metallic elements in the samples.

the symbols start with the same letter as the name of the element that is represented. A number of symbols, however, appear to have no connection with the names of the elements they represent (see Table 3.2). These symbols have been carried over from earlier names (usually in Latin) of the elements and are so firmly implanted in the literature that their use is continued today.

Special care must be taken in writing symbols. Capitalize only the first letter, and use a lowercase second letter if needed. This is important. For example, consider Co, the symbol for the element cobalt. If you write CO (capital C and capital O), you will have written the two elements carbon and oxygen (the *formula* for carbon monoxide), *not* the single element cobalt. Also, make sure that you write the letters distinctly; otherwise, Co (for cobalt) may be misread as Ca (for calcium).

Table 3.2 Symbols of the Elements Derived from Early Names*

Present name	Symbol	Former 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

*These symbols are in use today even though they do not correspond to the current name of the element.

Knowledge of symbols is essential for writing chemical formulas and equations, and will be needed in the remainder of this book and in any future chemistry courses you may take. One way to learn the symbols is to practice a few minutes a day by making flash cards of names and symbols and then practicing daily. Initially it is a good plan to learn the symbols of the most common elements shown in Table 3.1.

3.5 Introduction to the Periodic Table

Almost all chemistry classrooms have a chart called the *periodic table* hanging on the wall. It shows all the chemical elements and contains a great deal of useful information about them. As we continue our study of chemistry, we will learn much more about the periodic table. For now let's begin with the basics.

A simple version of the periodic table is shown in Table 3.3. Notice that in each box there is the symbol for the element and, above it, a number called the *atomic number*. For example nitrogen is 7 **N** and gold is 79 **Au**.

The elements are placed in the table in order of increasing atomic number in a particular arrangement designed by Dimitri Mendeleev in 1869. His arrangement organizes the elements with similar chemical properties in columns called families or **groups**. An example of this is the column

group

2 **He**
10 **Ne**
18 **Ar**
36 **Kr**
54 **Xe**
86 **Rn**

These elements are all gases and nonreactive. The group is called the **noble gases**. Other groups with special names are the **alkali metals** (under the 1A on the table), **alkaline earth metals** (Group 2A), and **halogens** (Group 7A).

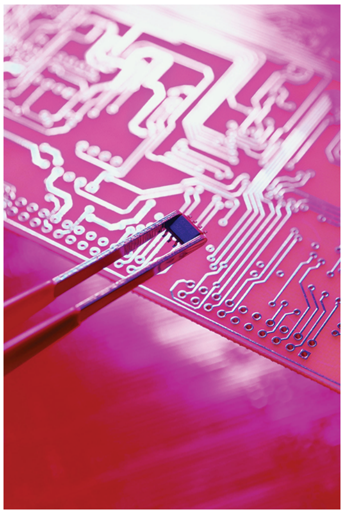
The tall columns of the periodic table (1A–7A and the noble gases) are known as the **representative elements**. Those elements in the center section of the periodic table and called **transition elements**.

noble gases
alkali metals
alkaline earth metals
halogens
representative elements
transition elements

Metals, Nonmetals, and Metalloids

metal

The elements can be classified as metals, nonmetals, and metalloids. Most of the elements are metals. We are familiar with them because of their widespread use in tools, construction materials, automobiles, and so on. But nonmetals are equally useful in our everyday life as major components of clothing, food, fuel, glass, plastics, and wood. Metalloids are often used in the electronics industry.



Tiny computer chips contain silicon, a metalloid.

The **metals** are solids at room temperature (mercury is an exception). They have high luster, are good conductors of heat and electricity, are *malleable* (can be rolled or hammered into sheets), and are *ductile* (can be drawn into wires). Most metals have a high melting point and high density. Familiar metals are aluminum, chromium, copper, gold, iron, lead, magnesium, mercury, nickel, platinum, silver, tin, and zinc. Less familiar but still important metals are calcium, cobalt, potassium, sodium, uranium, and titanium.

Metals have little tendency to combine with each other to form compounds. But many metals readily combine with nonmetals such as chlorine, oxygen, and sulfur to form compounds such as metallic chlorides, oxides, and sulfides. In nature, minerals are composed of the more reactive metals combined with other elements. A few of the less reactive metals such as copper, gold, and silver are sometimes found in a native, or free, state. Metals are often mixed with one another to form homogeneous mixtures of solids called alloys. Some examples are brass, bronze, steel, and coinage metals.

nonmetal

Nonmetals, unlike metals, are not lustrous, have relatively low melting points and densities, and are generally poor conductors of heat and electricity.

Carbon, phosphorus, sulfur, selenium, and iodine are solids; bromine is a liquid; the rest of the nonmetals are gases. Common nonmetals found uncombined in nature are carbon (graphite and diamond), nitrogen, oxygen, sulfur, and the noble gases (helium, neon, argon, krypton, xenon, and radon).

Nonmetals combine with one another to form molecular compounds such as carbon dioxide (CO_2), methane (CH_4), butane (C_4H_{10}), and sulfur dioxide (SO_2). Fluorine, the most reactive nonmetal, combines readily with almost all other elements.

metalloid

Several elements (boron, silicon, germanium, arsenic, antimony, tellurium, and polonium) are classified as **metalloids** and have properties that are intermediate between those of metals and those of nonmetals. The intermediate position of these elements is shown in Table 3.3. Certain metalloids, such as boron, silicon, and germanium, are the raw materials for the semiconductor devices that make the electronics industry possible.

Table 3.3 The Periodic Table

Metals
Metalloids
Nonmetals

1A	2A											3A	4A	5A	6A	7A	Noble gases
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							

*	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

3.6 Elements in Their Natural States

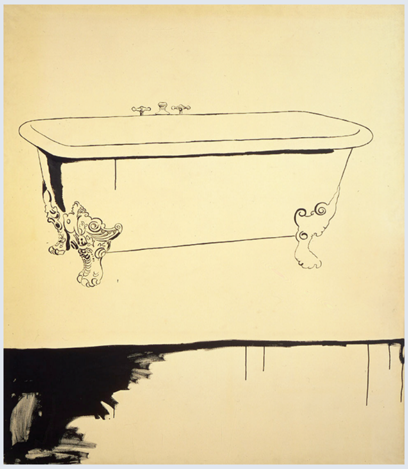
Most substances around us are mixtures or compounds. Elements tend to be reactive, and they combine with other elements to form compounds. It is rare to find elements in nature in pure form. There are some exceptions, however. Gold, for example, can be found as nuggets. Silver and platinum can also be found in nature in pure form. In fact, these metals are sometimes called the

CHEMISTRY IN ACTION • Using Oxygen to Revive Damaged Art

Treating damaged works of art is a tricky and time-consuming process that often produces mixed results. Now NASA has found a way to help bring damaged paintings back to life. NASA was breaking down oxygen molecules into oxygen atoms (a process that happens in nature in the upper atmosphere). The researchers were using the atomic oxygen to test the durability of satellite materials when they discovered that atomic oxygen could remove organic materials from the surface of objects without damaging the object. Bad news for satellite parts (which needed their coatings) but great news for the art world.

The chief conservator at the Cleveland Museum of Art tried the atomic oxygen treatment on two paintings damaged in a church fire in Cleveland. Although the paintings were not extremely valuable (and so were good subjects for an experiment), all other attempts to restore them had failed. Atomic oxygen proved to work wonders, and the soot and char came off to reveal the image below it. Since the treatment is a gas, the underlying layers were not harmed. The treatment doesn't work on everything and won't replace other techniques altogether, but the conservator was impressed enough to continue to work with NASA on the process.

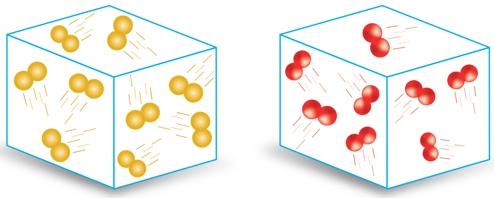
A small, portable atomic oxygen unit has also been built to treat artworks that have been damaged in a small area (by grafitti, etc.). A beam of atomic oxygen is applied directly to the damaged area to "spot clean" a piece of art. This technique was used to clean a lipstick mark from Andy Warhol's painting *Bathtub* (1961). A cosmetic party had been held at the Andy Warhol Museum in 1997. Free lipstick samples had been distributed at the party, and one reveler decided to kiss the painting! The painting was not varnished, so the lipstick stuck fast to the paint. After a day of treatment with the atomic oxygen beam, the lipstick mark was gone. Space technology can now be used to revive and restore art!



This famous Andy Warhol painting was spot cleaned by using a beam of atomic oxygen.

noble metals since they have a low reactivity. The noble gases are also not reactive and can be found in nature in uncombined form. Helium gas, for example, consists of tiny helium atoms moving independently.

Air can also be divided into its component gases. It is mainly composed of nitrogen and oxygen gases. But when we "look inside" these gases, we find tiny molecules (N_2 and O_2) instead of independent atoms like we see in the noble gases.

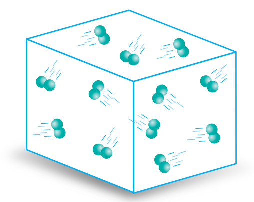


Nitrogen and oxygen gases are composed of molecules (N_2, ●●) and (O_2, ●●).

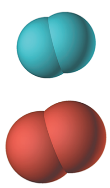
3.7 Elements That Exist as Diatomic Molecules

diatomic molecules

Diatomic molecules each contain exactly two atoms (alike or different). Seven elements in their uncombined state are **diatomic molecules**. Their symbols, formulas, and brief descriptions are listed in Table 3.4. Whether found free in nature or prepared in the laboratory, the molecules of these elements always contain two atoms. The formulas of the free elements are therefore always written to show this molecular composition: H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2.



Container of hydrogen molecules.



H_2 (blue) and O_2 (red) molecule.

Table 3.4 Elements That Exist as Diatomic Molecules

Element	Symbol	Molecular formula	Normal state
Hydrogen	H	H_2	Colorless gas
Nitrogen	N	N_2	Colorless gas
Oxygen	O	O_2	Colorless gas
Fluorine	F	F_2	Pale yellow gas
Chlorine	Cl	Cl_2	Yellow-green gas
Bromine	Br	Br_2	Reddish-brown liquid
Iodine	I	I_2	Bluish-black solid

It is important to see that symbols can designate either an atom or a molecule of an element. Consider hydrogen and oxygen. Hydrogen gas is present in volcanic gases and can be prepared by many chemical reactions. Regardless of their source, all samples of free hydrogen gas consist of diatomic molecules.

Free hydrogen is designated by the formula H_2, which also expresses its composition. Oxygen makes up about 21% by volume of the air that we breathe. This free oxygen is constantly being replenished by photosynthesis; it can also be prepared in the laboratory by several reactions. The majority of free oxygen is diatomic and is designated by the formula O_2. Now consider water, a compound designated by the formula H_2O (sometimes HOH). Water contains neither free hydrogen (H_2) nor free oxygen (O_2). The H_2 part of the formula H_2O simply indicates that two atoms of hydrogen are combined with one atom of oxygen to form water.

Symbols are used to designate elements, show the composition of molecules of elements, and give the elemental composition of compounds.

Practice 3.1

Identify the physical state of each of the following elements at room temperature (20°C):

H, Na, Ca, N, S, Fe, Cl, Br, Ne, Hg

Hint: You may need to use a resource (such as the Internet or a chemical handbook) to assist you.

Practice 3.2

Identify each of the following elements as a nonmetal, metal, or metalloid:

Na, F, Cr, Mo, Kr, Si, Cu, Sb, I, S

3.8 Compounds

compound

A **compound** is a distinct substance that contains two or more elements chemically combined in a definite proportion by mass. Compounds, unlike elements, can be decomposed chemically into simpler substances—that is, into simpler compounds and/or elements. Atoms of the elements in a compound are combined in whole-number ratios, never as fractional parts. Compounds fall into two general types, *molecular* and *ionic*. Figure 3.3 illustrates the classification of compounds.

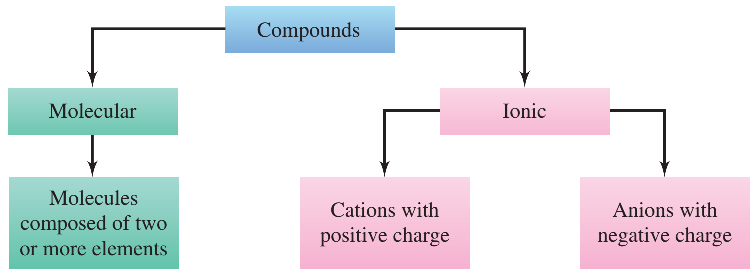


Figure 3.3
Compounds can be classified as molecular or ionic. Ionic compounds are held together by attractive forces between their positive and negative charges. Molecular compounds are held together by covalent bonds.

molecule

A **molecule** is the smallest uncharged individual unit of a compound formed by the union of two or more atoms. Water is a typical molecular compound. If we divide a drop of water into smaller and smaller particles, we finally obtain a single molecule of water consisting of two hydrogen atoms bonded to one oxygen atom, as shown in Figure 3.4a. This molecule is the ultimate particle of water; it cannot be further subdivided without destroying the water molecule and forming hydrogen and oxygen.

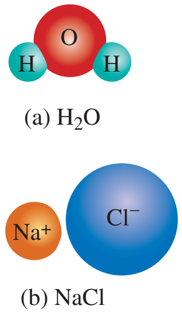


Figure 3.4
Representation of molecular and ionic (nonmolecular) compounds. (a) Two hydrogen atoms combined with an oxygen atom to form a molecule of water. (b) A positively charged sodium ion and a negatively charged chloride ion form the compound sodium chloride.

ion
cation
anion

An **ion** is a positively or negatively charged atom or group of atoms. An ionic compound is held together by attractive forces that exist between positively and negatively charged ions. A positively charged ion is called a **cation** (pronounced *cat-eye-on*); a negatively charged ion is called an **anion** (pronounced *an-eye-on*).

Sodium chloride is a typical ionic compound. The ultimate particles of sodium chloride are positively charged sodium ions and negatively charged chloride ions, shown in Figure 3.4b. Sodium chloride is held together in a crystalline structure by the attractive forces existing between these oppositely charged ions. Although ionic compounds consist of large aggregates of cations and anions, their formulas are normally represented by the simplest possible ratio of the atoms in the compound. For example, in sodium chloride the ratio is one sodium ion to one chlorine ion, so the formula is NaCl.

There are more than 11 million known registered compounds, with no end in sight as to the number that will be prepared in the future. Each compound is unique and has characteristic properties. Let's consider two compounds, water and sodium chloride, in some detail. Water is a colorless, odorless, tasteless liquid that can be changed to a solid (ice) at 0°C and to a gas (steam) at 100°C. Composed of two atoms of hydrogen and one atom of oxygen per molecule, water is 11.2% hydrogen and 88.8% oxygen by mass. Water reacts chemically with sodium to produce hydrogen gas and sodium hydroxide, with lime to produce calcium hydroxide, and with sulfur trioxide to produce sulfuric acid. When water is decomposed, it forms hydrogen and oxygen molecules (see Figure 3.5). No other compound has all these exact physical and chemical properties; they are characteristic of water alone.

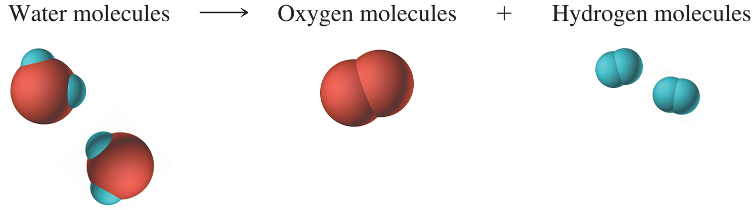


Figure 3.5
A representation of the decomposition of water into oxygen and hydrogen molecules.

CHEMISTRY IN ACTION • Cars: Is Hydrogen the Answer?

The increasing cost of petroleum and the increased pollution in our cities have sparked a race to find alternative fuels for our cars. Manufacturers agree that the best choice for automobiles of the future is hydrogen fuel cells. The greatest controversy now is how to obtain and deliver the hydrogen required for the fuel cells.

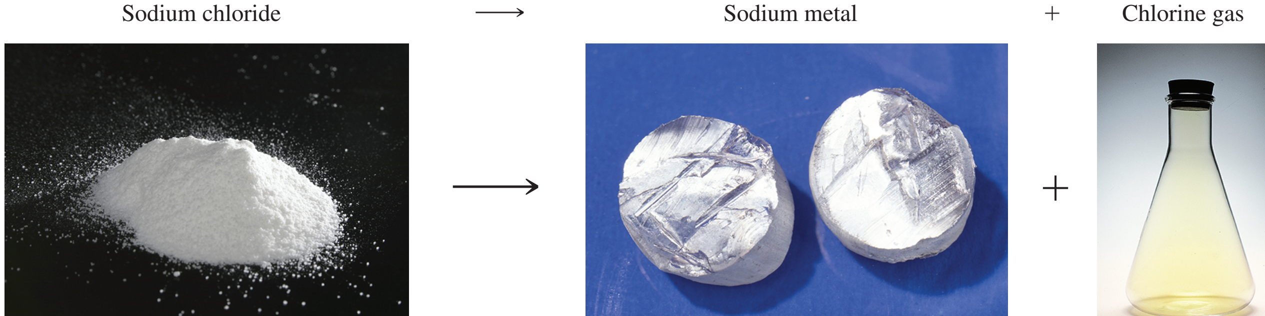
General Motors scientists are working to get hydrogen by "cracking," or re-forming, gasoline. Basically, larger hydrocarbon molecules are cracked, or broken down, to produce hydrogen and smaller hydrocarbons. This could be accomplished right onboard the vehicle. In fact, a Chevrolet S-10 truck has been designed as a fuel cell/battery hybrid. The fuel cell gets hydrogen from an onboard re-former, but the re-former and fuel cell equipment take up half the truck's bed. After adding batteries (for acceleration), the total weight of the truck is about 6300 pounds! The good news is the fuel economy is 40 miles per gallon with a range of 525 miles. This combined with the possibility of re-forming the gasoline or natural gas into hydrogen at gas stations (once enough hybrid vehicles are on the road) give General Motors optimism to continue development.

Chrysler Town and Country Natrium fuel cell vehicle.

DaimlerChrysler is also working on fuel cells using another process. The company's engineers plan to bypass fossil fuels altogether. In March 2002, the firm unveiled the Natrium fuel cell Town and Country minivan prototype. This electric van is fueled by hydrogen obtained from a noncombustible aqueous solution of sodium borohydride. The liquid is carried in a large fuel tank and is re-formed onboard to release hydrogen to the fuel cells. Since Natrium uses a nonfossil fuel and has a range of 300 miles without taking up passenger and cargo space, DaimlerChrysler plans to continue development in this direction. The biggest hurdle to overcome is the lack of an economic means to get the fuel from a borax mine to a filling station. Hopefully, one or both of these methods will produce economical alternatives to our present-day automobiles.

Sodium chloride is a colorless crystalline substance with a ratio of one atom of sodium to one atom of chlorine. Its composition by mass is 39.3% sodium and 60.7% chlorine. It does not conduct electricity in its solid state; it dissolves in water to produce a solution that conducts electricity. When a current is passed through molten sodium chloride, solid sodium and gaseous chlorine are produced (see Figure 3.6). These specific properties belong to sodium

Sodium chloride ⟶ Sodium metal + Chlorine gas



(a) (b) (c)

Figure 3.6
When sodium chloride (a) is decomposed, it forms sodium metal (b) and chlorine gas (c).

chloride and to no other substance. Thus, a compound may be identified and distinguished from all other compounds by its characteristic properties. We consider these chemical properties further in Chapter 4.

3.9 Chemical Formulas

chemical formula

Chemical formulas are used as abbreviations for compounds. A **chemical formula** shows the symbols and the ratio of the atoms of the elements in a compound. Sodium chloride contains one atom of sodium per atom of chlorine; its formula is NaCl. The formula for water is H_2O; it shows that a molecule of water contains two atoms of hydrogen and one atom of oxygen.

subscript

The formula of a compound tells us which elements it is composed of and how many atoms of each element are present in a formula unit. For example, a unit of sulfuric acid is composed of two atoms of hydrogen, one atom of sulfur, and four atoms of oxygen. We could express this compound as HHSOOOO, but this is cumbersome, so we write H_2SO_4 instead. The formula may be expressed verbally as "H-two-S-O-four." Numbers that appear partially below the line and to the right of a symbol of an element are called **subscripts**. Thus, the 2 and the 4 in H_2SO_4 are subscripts (See Figure 3.7). Characteristics of chemical formulas are as follows:

1. The formula of a compound contains the symbols of all the elements in the compound.
2. When the formula contains one atom of an element, the symbol of that element represents that one atom. The number 1 is not used as a subscript to indicate one atom of an element.

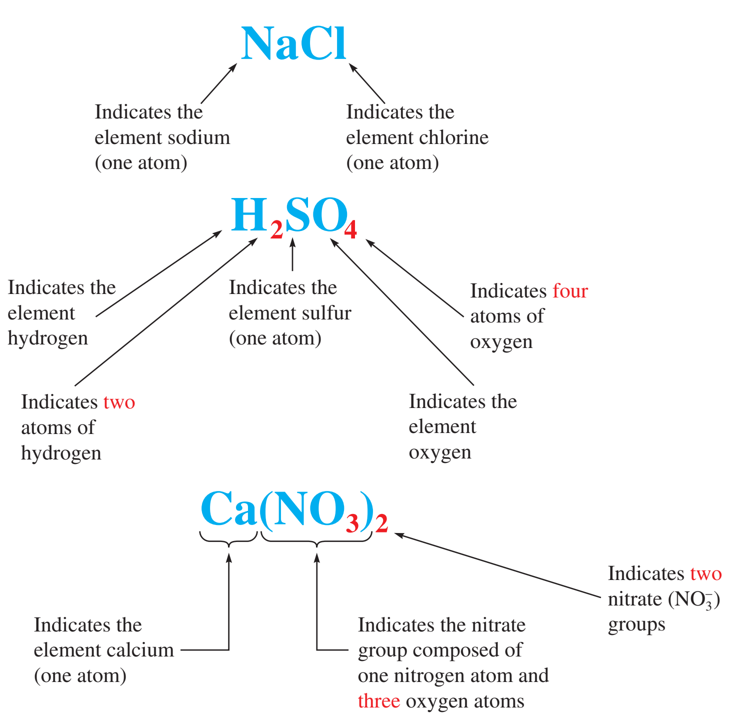


Figure 3.7
Explanation of the formulas NaCl, H_2SO_4, and $Ca(NO_3)_2$.

3. When the formula contains more than one atom of an element, the number of atoms is indicated by a subscript written to the right of the symbol of that atom. For example, the 2 in H_2O indicates two atoms of H in the formula.
4. When the formula contains more than one of a group of atoms that occurs as a unit, parentheses are placed around the group, and the number of units of the group is indicated by a subscript placed to the right of the parentheses. Consider the nitrate group, NO_3^-. The formula for sodium nitrate, $NaNO_3$, has only one nitrate group, so no parentheses are needed. Calcium nitrate, $Ca(NO_3)_2$, has two nitrate groups, as indicated by the use of parentheses and the subscript 2. $Ca(NO_3)_2$ has a total of nine atoms: one Ca, two N, and six O atoms. The formula $Ca(NO_3)_2$ is read as "C-A [pause] N-O-three taken twice."
5. Formulas written as H_2O, H_2SO_4, $Ca(NO_3)_2$, and $C_{12}H_{22}O_{11}$ show only the number and kind of each atom contained in the compound; they do not show the arrangement of the atoms in the compound or how they are chemically bonded to one another.

Practice 3.3

How would you read these formulas aloud?
(a) KBr (b) $PbCl_2$ (c) $CaCO_3$ (d) $Mg(OH)_2$

Example 3.1 Write formulas for the following compounds; the atomic composition is given. (a) hydrogen chloride: 1 atom hydrogen + 1 atom chlorine; (b) methane: 1 atom carbon + 4 atoms hydrogen; (c) glucose: 6 atoms carbon + 12 atoms hydrogen + 6 atoms oxygen.

SOLUTION

(a) First write the symbols of the atoms in the formula: H Cl. Since the ratio of atoms is one to one, we bring the symbols together to give the formula for hydrogen chloride as HCl.
(b) Write the symbols of the atoms: C H. Now bring the symbols together and place a subscript 4 after the hydrogen atom. The formula is CH_4.
(c) Write the symbols of the atoms: C H O. Now write the formula, bringing together the symbols followed by the correct subscripts according to the data given (six C, twelve H, six O). The formula is $C_6H_{12}O_6$.

Chapter 3 Review

3.1 Elements

KEY TERMS

Element
Atom

- All matter consists of about 100 elements.
- An element is a fundamental chemical substance.
- The smallest particle of an element is an atom.
- Elements cannot be broken down by chemical means to a simpler substance.

3.2 Distribution of Elements

- Chemical elements are not distributed equally in nature.
- Hydrogen is the most abundant element in the universe.
- Oxygen is the most abundant element on the Earth and in the human body.

3.3 Names of the Elements

- Names for the chemical elements come from a variety of sources, including Latin, location of discovery, and famous scientists.

3.4 Symbols of the Elements

KEY TERM

Symbols

- Rules for writing symbols for the elements are:
  - One or two letters
  - If one letter, use a capital
  - If two letters, only the first is a capital

3.5 Introduction to the Periodic Table

KEY TERMS

Group	Representative elements
Noble gases	Transition elements
Alkali metals	Metals
Alkaline earth metal	Nonmetals
Halogens	Metalloids

- The periodic table was designed by Dimitri Mendeleev and arranges the elements according to their atomic numbers and in groups by their chemical properties.
- Elements can be classified as representative or as transition elements.
- Elements can also be classified by special groups with similar chemical properties. Such groups include the noble gases, alkali metals, alkaline earth metals, and halogens.
- Elements can be classified as metals, nonmetals, or metalloids:
  - Most elements are metals.
  - Metals have the following properties:
    - High luster
    - Good conductor of heat and electricity
    - Malleable
  - Nonmetals have the following properties:
    - Not lustrous
    - Poor conductors of heat and electricity

3.6 Elements in Their Natural States

- Most elements are found in nature combined with other elements.
- Elements that are found in uncombined form in nature include gold, silver, copper, and platinum as well as the noble gases (He, Ne, Ar, Kr, Xe, Rn).

3.7 Elements That Exist as Diatomic Molecules

KEY TERM

Diatomic molecules

- Diatomic molecules contain exactly two atoms (alike or different).
- Seven elements exist as diatomic molecules—H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2.

3.8 Compounds

KEY TERMS

Compound
Molecule
Ion
Cation
Anion

- A compound is a substance that contains two or more elements chemically combined in a definite proportion by mass.
- There are two general types of compounds:
  - Molecular—formed of individual molecules composed of atoms
  - Ionic—formed from ions that are either positive or negative
    - Cation—positively charged ion
    - Anion—negatively charged ion

3.9 Chemical Formulas

KEY TERMS

Chemical formula
Subscript

- A chemical formula shows the symbols and the ratios of atoms for the elements in a chemical compound.
- Characteristics of chemical formulas include:
  - It contains symbols of all elements in the compound.
  - The symbol represents one atom of the element.
  - If more than one atom of an element is present, the number of atoms is indicated by a subscript.
  - Parentheses are used to show multiple groups of atoms occurring as a unit in the compound.
  - A formula does not show the arrangement of the atoms in the compound.

Review Questions

All questions with blue numbers have answers in the appendix of the text.

1. Are there more atoms of silicon or hydrogen in the Earth's crust, seawater, and atmosphere? Use Figure 3.2 and the fact that the mass of a silicon atom is about 28 times that of a hydrogen atom.
2. Give the symbols for each of the following elements:
   (a) silver (e) iron
   (b) oxygen (f) nitrogen
   (c) hydrogen (g) magnesium
   (d) carbon (h) potassium
3. Give the names for each of these elements:
   (a) Na (e) Ne
   (b) F (f) He
   (c) Ni (g) Ca
   (d) Zn (h) Cl
4. What does the symbol of an element stand for?
5. Write down what you believe to be the symbols for the elements phosphorus, aluminum, hydrogen, potassium, magnesium, sodium, nitrogen, nickel, and silver. Check yourself by looking up the correct symbols in Table 3.1.

6. Interpret the difference in meanings for each of these pairs: (a) Si and SI (b) Pb and PB (c) 4 P and P_4
7. List six elements and their symbols in which the first letter of the symbol is different from that of the name. (Table 3.2)
8. Write the names and symbols for the 14 elements that have only one letter as their symbol. (See periodic table on inside front cover.)
9. Distinguish between an element and a compound.
10. How many metals are there? nonmetals? metalloids? (Table 3.3)
11. Of the ten most abundant elements in the Earth's crust, seawater, and atmosphere, how many are metals? nonmetals? metalloids? (Figure 3.2)
12. Of the six most abundant elements in the human body, how many are metals? nonmetals? metalloids? (Figure 3.2)
13. Why is the symbol for gold Au rather than G or Go?
14. Give the names of (a) the solid diatomic nonmetal and (b) the liquid diatomic nonmetal. (Table 3.4)
15. Distinguish between a compound and a mixture.
16. What are the two general types of compounds? How do they differ from each other?
17. What is the basis for distinguishing one compound from another?
18. What is the major difference between a cation and an anion?
19. Write the names and formulas of the elements that exist as diatomic molecules. (Table 3.4)

Paired Exercises

All exercises with blue numbers have answers in the appendix of the text.

1. Which of the following are diatomic molecules?
   (a) Cl_2 (b) CO (c) CCl_4 (d) NO_2 (e) N_2 (f) HBr (g) ClO_2 (h) H_2O

2. Which of the following are diatomic molecules?
   (a) CO_2 (b) H_2S (c) H_2 (d) P_4 (e) CS_2 (f) NO (g) ClF

3. What elements are present in each compound?
   (a) potassium iodide KI
   (b) sodium carbonate Na_2CO_3
   (c) aluminum oxide Al_2O_3
   (d) calcium bromide $CaBr_2$
   (e) acetic acid $HC_2H_3O_2$

4. What elements are present in each compound?
   (a) magnesium bromide $MgBr_2$
   (b) carbon tetrachloride CCl_4
   (c) nitric acid HNO_3
   (d) barium sulfate $BaSO_4$
   (e) aluminum phosphate $AlPO_4$

5. Write the formula for each compound (the composition is given after each name):
   (a) zinc oxide — 1 atom Zn, 1 atom O
   (b) potassium chlorate — 1 atom K, 1 atom Cl, 3 atoms O
   (c) sodium hydroxide — 1 atom Na, 1 atom O, 1 atom H
   (d) ethyl alcohol — 2 atoms C, 6 atoms H, 1 atom O

6. Write the formula for each compound (the composition is given after each name):
   (a) aluminum bromide — 1 atom Al, 3 atoms Br
   (b) calcium fluoride — 1 atom Ca, 2 atoms F
   (c) lead(II) chromate — 1 atom Pb, 1 atom Cr, 4 atoms O
   (d) benzene — 6 atoms C, 6 atoms H

7. Explain the meaning of each symbol and number in these formulas:
   (a) H_2O
   (b) Na_2SO_4
   (c) $HC_2H_3O_2$

8. Explain the meaning of each symbol and number in these formulas:
   (a) $AlBr_3$
   (b) $Ni(NO_3)_2$
   (c) $C_{12}H_{22}O_{11}$ (sucrose)

9. How many atoms are represented in each formula?
   (a) KF (b) $CaCO_3$ (c) $K_2Cr_2O_7$ (d) $NaC_2H_3O_2$ (e) $(NH_4)_2C_2O_4$

10. How many atoms are represented in each formula?
   (a) NaCl (b) N_2 (c) $Ba(ClO_3)_2$ (d) CCl_2F_2 (Freon) (e) $Al_2(SO_4)_3$

11. How many atoms of oxygen are represented in each formula?
   (a) H_2O (b) $CuSO_4$ (c) H_2O_2 (d) $Fe(OH)_3$ (e) $Al(ClO_3)_3$

12. How many atoms of hydrogen are represented in each formula?
   (a) H_2 (b) $Ba(C_2H_3O_2)_2$ (c) $C_6H_{12}O_6$ (d) $HC_2H_3O_2$ (e) $(NH_4)_2Cr_2O_7$

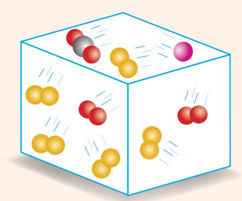
13. Identify each of the following as a pure substance or a mixture:
(a) a bottle of Gatorade (d) coffee
(b) aluminum (e) fluorine gas
(c) a piece of bread (f) potassium carbonate

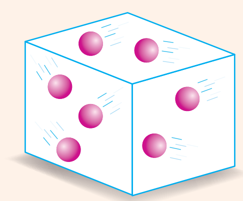
14. Identify each of the following as a pure substance or a mixture:
(a) the human body (d) copper
(b) bottled spring water (e) Mountain Dew
(c) aluminum oxide (f) oak wood

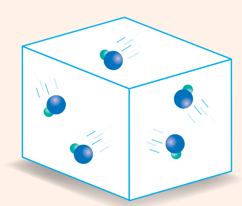
15. For Question 13, state whether each pure substance is an element or a compound.

16. For Question 14, state whether each pure substance is an element or a compound.

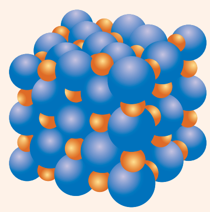
17. Classify each of the following as an element, compound, or mixture:

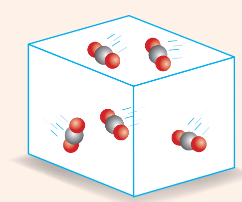

(a)

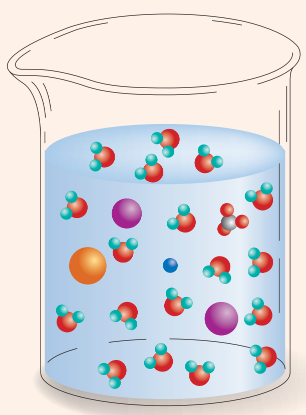

(c)


(b)

18. Classify each of the following as an element, compound, or mixture:


(a)


(b)


(c)

19. Classify each material as an element, compound, or mixture:
(a) xenon (c) crude oil
(b) sugar (d) nitric acid

20. Classify each material as an element, compound, or mixture:
(a) carbon monoxide (c) mouthwash
(b) iced tea (d) nickel

21. Is there a pattern to the location of the gaseous elements on the periodic table? If so, describe it.

22. Is there a pattern to the location of the liquid elements on the periodic table? If so, describe it.

23. What percent of the first 36 elements on the periodic table are metals?

24. What percent of the first 36 elements on the periodic table are solids at room temperature?

Additional Exercises

All exercises with blue numbers have answers in the appendix of the text.

25. Consider a homogeneous mixture of salt dissolved in water. What method could you use to separate the two components of the mixture?

26. Consider a heterogeneous mixture of golf balls, tennis balls, and footballs. What method could you use to separate the three components of the mixture?

27. You accidentally poured salt into your large grind pepper shaker. This is the only pepper that you have left and you need it to cook a meal, but you don't want the salt to be mixed in. How can you successfully separate these two components?

28. On the periodic table at the front of this book, do you notice anything about the atoms that make up the following ionic compounds: NaCl, KI, and $MgBr_2$? (*Hint:* Look at the position of the atoms in the given compounds on the periodic table.)

29. How many total atoms are present in each of the following compounds?
(a) CO
(b) BF_3
(c) HNO_3
(d) $KMnO_4$
(e) $Ca(NO_3)_2$
(f) $Fe_3(PO_4)_2$

30. The formula for vitamin B_{12} is $C_{63}H_{88}CoN_{14}O_{14}P$.
(a) How many atoms make up one molecule of vitamin B_{12}?
(b) What percentage of the total atoms are carbon?
(c) What fraction of the total atoms are metallic?

***31.** It has been estimated that there is 4×10^{-4} mg of gold per liter of seawater. At a price of \$19.40/g, what would be the value of the gold in 1 km^3 (1×10^{15} cm^3) of the ocean?

32. Calcium dihydrogen phosphate is an important fertilizer. How many atoms of hydrogen are there in ten formula units of $Ca(H_2PO_4)_2$?

33. How many total atoms are there in one molecule of $C_{145}H_{293}O_{168}$?

34. Name the following:
(a) three elements, all metals, beginning with the letter M
(b) four elements, all solid nonmetals
(c) five elements, all solids in the first five rows of the periodic table, whose symbols start with letters different from the element name.

35. How would you separate a mixture of sugar and sand and isolate each in its pure form?

36. How many total atoms are there in seven dozen molecules of nitric acid, HNO_3?

37. Make a graph using the data below. Plot the density of air in grams per liter along the *x*-axis and temperature along the *y*-axis.

Temperature (°C)	Density (g/L)
0	1.29
10	1.25
20	1.20
40	1.14
80	1.07

(a) What is the relationship between density and temperature according to your graph?
(b) From your plot, find the density of air at these temperatures:
5°C 25°C 70°C

38. These formulas look similar but represent different things.

8 S S_8

Compare and contrast them. How are they alike? How are they different?

39. Write formulas for the following compounds that a colleague read to you:
(a) NA-CL
(b) H2-S-O4
(c) K2-O
(d) Fe2-S3
(e) K3-P-O4
(f) CA (pause) CN taken twice
(g) C6-H12-O6
(h) C2-H5 (pause) OH
(i) CR (pause) NO3 taken three times

40. The abundance of iodine in seawater is 5.0×10^{-8} % by mass. How many kilograms of seawater must be treated to obtain 1.0 g iodine?

Challenge Exercises

All exercises with blue numbers have answers in the appendix of the text.

***41.** Write the chemical formulas of the neutral compounds that would result if the following ions were combined. Use the Charges of Common Ions table on the inside back cover of the book to help you.
(a) ammonium ion and chloride ion
(b) hydrogen ion and hydrogen sulfate ion
(c) magnesium ion and iodide ion
(d) iron(II) ion and fluoride ion
(e) lead(II) ion and phosphate ion
(f) aluminum ion and oxide ion

***42.** Write formulas of all the compounds that will form between the first five of the Group 1A and 2A metals and the oxide ion.

Answers to Practice Exercises

3.1

gases	H, N, Cl, Ne
liquids	Br, Hg
solids	Na, Cu, S, Fe

3.2

nonmetal	F, Kr, I, S
metal	Na, Cr, Mo, Cu
metalloid	Si, Sb

3.3 (a) K–BR
(b) P–B–CL–2
(c) CA (pause) CO–3
(d) MG (pause) OH taken twice