# Molecules and Compounds

"Almost all aspects of life are engineered at the molecular level, and without understanding molecules, we can only have a very sketchy understanding of life itself."

Francis Harry Compton Crick (1916–2004)

### 5.1 Sugar and Salt

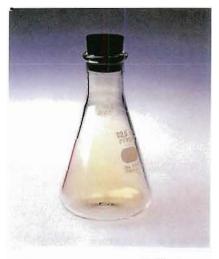
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### 5.1 Sugar and Salt

Sodium, a shiny metal ( Figure 5.1) that dulls almost instantly upon exposure to air, is extremely reactive and poisonous. If you were to consume any appreciable amount of elemental sodium, you would need immediate medical help. Chlorine, a pale yellow gas ( Figure 5.2), is equally reactive and poisonous. Yet the compound formed from these two elements, sodium chloride, is the relatively harmless flavor enhancer that we call table salt ( Figure 5.3). When elements combine to form compounds, their properties change completely.



A Figure 5.1 Elemental sodium Sodium is an extremely reactive metal that dulls almost instantly upon exposure to air.



▲ Figure 5.2 Elemental chlorine
Chlorine is a yellow gas with a pungent
odor. It is highly reactive and poisonous.

◀ Ordinary table sugar is a compound called sucrose. A sucrose molecule, such as the one shown here, contains carbon, hydrogen, and oxygen atoms. The properties of sucrose are, however, very different from those of carbon, hydrogen, and oxygen. The properties of a compound are, in general, different from the properties of the elements that compose it.

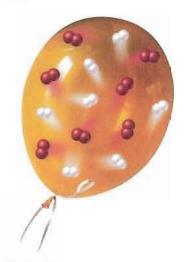
Figure 5.3 Sodium chloride
The compound formed by sodium and chlorine is table salt.



Consider ordinary sugar. Sugar is a compound composed of carbon, hydrogen, and oxygen. Each of these elements has its own unique properties. Carbon is most familiar to us as the graphite found in pencils or as the diamonds in jewelry. Hydrogen is an extremely flammable gas used as a fuel for the space shuttle, and oxygen is one of the gases that compose air. When these three elements combine to form sugar, however, a sweet, white, crystalline solid results.

In Chapter 4, we learned how protons, neutrons, and electrons combine to form different elements, each with its own properties and its own chemistry, each different from the other. In this chapter, we learn how these elements combine with each other to form different compounds, each with its own properties and its own chemistry, each different from all the others and different from the elements that compose it. Here is the great wonder of nature, how from such simplicity—protons, neutrons, and electrons—we get such great complexity. It is exactly this complexity, however, that makes life possible. Life could not exist with just ninety-one different elements if they did not combine to form compounds. It takes compounds in all of their diversity to make living organisms.

### 5.2 Compounds Display Constant Composition



▲ Figure 5.4 A mixture This balloon is filled with a mixture of hydrogen and oxygen gas. The relative amounts of hydrogen and oxygen are variable. We could easily add either more hydrogen or more oxygen to the balloon.

Although some of the substances we encounter in everyday life are elements, most are not—they are compounds. Free atoms are rare in nature. As Chapter 3 describes, a compound is different from a mixture of elements. In a compound, the elements combine in fixed, definite proportions, whereas in a mixture, they can have any proportions whatsoever. For example, consider the difference between a mixture of hydrogen and oxygen gas ( Figure 5.4), and the compound water ( Figure 5.5). A mixture of hydrogen and oxygen gas can have any proportions of hydrogen and oxygen. Water, on the other hand, is composed of water molecules that consist of two hydrogen atoms bonded to one oxygen atom. Consequently, water has a definite proportion of hydrogen to oxygen.

The first chemist to formally state the idea that elements combine in fixed proportions to form compounds was Joseph Proust (1754–1826) in the law of constant composition, which states:

All samples of a given compound have the same proportions of their constituent elements.

For example, if we decompose water, we find 16.0 g of oxygen to every 2.0 g of hydrogen, or an oxygen-to-hydrogen mass ratio of:

Mass ratio = 
$$\frac{16.0 \text{ g O}}{2.0 \text{ g H}} = 8.0$$



◀ Figure 5.5 A chemical compound
This balloon is filled with water, composed of molecules that have a fixed ratio of hydrogen to oxygen.
(Source: JoLynn E. Funk.)



2 H atoms ( ) to every 1 O atom ( )

Figure 5.6 Compounds have fixed composition Water will always have a constant ratio of hydrogen to oxygen, no matter what its source.

Even though atoms combine in wholenumber ratios, their mass ratios are not necessarily whole numbers. This is true of any sample of pure water, no matter what its origin ( Figure 5.6). The law of constant composition applies not only to water, but to every compound. Consider ammonia, a compound composed of nitrogen and hydrogen. Ammonia contains 14.0 g of nitrogen to every 3.0 g of hydrogen, or a nitrogen-to-hydrogen mass ratio of:

Mass ratio = 
$$\frac{14.0 \text{ g N}}{3.0 \text{ g H}} = 4.7$$

Again, this ratio is the same for every sample of ammonia—the composition of each compound is constant.

#### **EXAMPLE 5.1** Constant Composition of Compounds

Two samples of carbon dioxide, obtained from different sources, were decomposed into their constituent elements. One sample produced 4.8 g of oxygen and 1.8 g of carbon, and the other sample produced 17.1 g of oxygen and 6.4 g of carbon. Show that these results are consistent with the law of constant composition.

Compute the mass ratio of one element to the other by dividing the larger mass by the smaller one. For the first sample:	Solution: $\frac{\text{Mass oxygen}}{\text{Mass carbon}} = \frac{4.8 \text{ g}}{1.8 \text{ g}} = 2.7$
For the second sample:	$\frac{\text{Mass oxygen}}{\text{Mass carbon}} = \frac{17.1 \text{ g}}{6.4 \text{ g}} = 2.7$

Since the ratios are the same for the two samples, these results are consistent with the law of constant composition.

#### SKILLBUILDER 5.1 Constant Composition of Compounds

Two samples of carbon monoxide, obtained from different sources, were decomposed into their constituent elements. One sample produced 4.3 g of oxygen and 3.2 g of carbon, and the other sample produced 7.5 g of oxygen and 5.6 g of carbon. Are these results consistent with the law of constant composition?

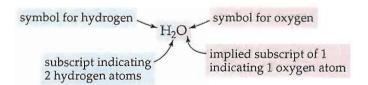
FOR MORE PRACTICE Example 5.16; Problems 23, 24.

### 5.3

### **Chemical Formulas: How to Represent Compounds**

Compounds have constant composition with respect to mass (as we learned in the previous section) because they are composed of atoms in fixed ratios.

We represent a compound with a **chemical formula**, which indicates the elements present in the compound and the relative number of atoms of each. For example,  $H_2O$  is the chemical formula for water; it indicates that water consists of hydrogen and oxygen atoms in a 2:1 ratio. The formula contains the symbol for each element, accompanied by a subscript indicating the number of atoms of that element. By convention, a subscript of 1 is omitted.



Other common chemical formulas include NaCl for table salt, indicating sodium and chlorine atoms in a 1:1 ratio; CO<sub>2</sub> for carbon dioxide, indicating carbon and oxygen atoms in a 1:2 ratio; and C<sub>12</sub>H<sub>22</sub>O<sub>11</sub> for table sugar (sucrose), indicating carbon, hydrogen, and oxygen atoms in a 12:22:11 ratio. The subscripts in a chemical formula are part of the compound's definition—if they change, the formula no longer specifies the same compound. For example, CO is the chemical formula for carbon monoxide, an air pollutant with adverse health effects on humans. When inhaled, carbon monoxide interferes with the blood's ability to carry oxygen, which can be fatal. CO is the primary substance responsible for deaths of people who inhale too much automobile exhaust. If you change the subscript of the O in CO from 1 to 2, however, you get the formula for a totally different compound. CO<sub>2</sub> is the chemical formula for carbon dioxide, the relatively harmless product of combustion and human respiration. We breathe small amounts of CO<sub>2</sub> all the time with no harmful effects. So, remember:

The subscripts in a chemical formula represent the relative numbers of each type of atom in a chemical compound; they never change for a given compound.

Chemical formulas normally list the most metallic elements first. Therefore, the formula for table salt is NaCl, not ClNa. For compounds that do not include a metal, the more metal-like element is listed first. Recall from Chapter 4 that metals are found on the left side of the periodic table and nonmetals on the upper right side. Therefore, among nonmetals, those to the left in the periodic table are more metal-like than those to the right and are normally listed first. Therefore we write CO<sub>2</sub> and NO, not O<sub>2</sub>C and ON. Within a single column in the periodic table, elements toward the bottom are more metal-like than elements toward the top. Therefore we write SO<sub>2</sub>, not O<sub>2</sub>S. The specific order for listing nonmetal elements in a chemical formula is shown in Table 5.1.



▲ The subscripts in a chemical formula are part of what define the compound—if you change a subscript, you change the compound.

There are a few historical exceptions to the practice in which the most metallic element is named first, such as the hydroxide ion, which is written as OH<sup>-</sup>.

TABLE 5.1 Order of Listing Nonmetal Elements in a Chemical Formula

C P N H S I Br Cl O F Elements on the left are generally listed before elements on the right.

#### **EXAMPLE 5.2** Writing Chemical Formulas

Write a chemical formula for each of the following:

- (a) the compound containing two aluminum atoms to every three oxygen atoms
- (b) the compound containing three oxygen atoms to every sulfur atom
- (c) the compound containing four chlorine atoms to every carbon atom

Since aluminum is the metal, it is listed first.	Solution: (a) Al <sub>2</sub> O <sub>3</sub>
Since sulfur is below oxygen on the periodic table and since it occurs before oxygen in Table 5.1, it is listed first.	(b) SO <sub>3</sub>
Since carbon is to the left of chlorine on the periodic table and since it occurs before chlorine in Table 5.1, it is listed first.	(c) CCl <sub>4</sub>

#### SKILLBUILDER 5.2 Writing Chemical Formulas

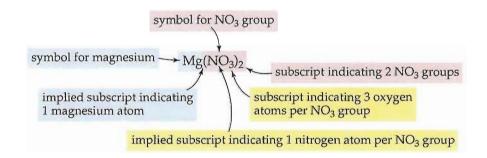
Write a chemical formula for each of the following:

- (a) the compound containing two silver atoms to every sulfur atom
- (b) the compound containing two nitrogen atoms to every oxygen atom
- (c) the compound containing two oxygen atoms to every titanium atom

FOR MORE PRACTICE Example 5.17; Problems 29, 30, 31, 32.

Many groups of atoms have a charge associated with them; charged groups are called polyatomic ions. For example, the NO<sub>3</sub> group has a negative charge, NO<sub>3</sub><sup>-</sup>. Polyatomic ions are described in more detail in Section 5.7.

Some chemical formulas contain groups of atoms that act as a unit. When several groups of the same kind are present, their formula is set off in parentheses with a subscript to indicate the number of that group. For example,  $Mg(NO_3)_2$  indicates a compound containing one magnesium atom and two  $NO_3$  groups.



To determine the total number of each type of atom within the parentheses, multiply the subscript outside the parentheses by the subscript for each atom inside the parentheses. Therefore, the preceding formula has the following numbers of each type of atom.

Mg:	1 Mg	
N:	$1 \times 2 = 2 N$	(implied 1 inside parentheses times 2 outside parentheses)
O:	$3 \times 2 = 6  \mathrm{O}$	(3 inside parentheses times 2 outside parentheses)

#### **EXAMPLE 5.3**

### Total Number of Each Type of Atom in a Chemical Formula

Determine the number of each type of atom in  $Mg_3(PO_4)_2$ .

#### Solution:

Mg: There are three Mg atoms, as indicated by the subscript 3.

P: There are two P atoms, as we see by multiplying the subscript outside

the parentheses (2) by the subscript for P inside the parentheses, which

is 1 (implied).

O: There are eight O atoms, as we see by multiplying the subscript outside

the parentheses (2) by the subscript for O inside the parentheses (4).

### SKILLBUILDER 5.3 Total Number of Each Type of Atom in a Chemical Formula

Determine the number of each type of atom in K<sub>2</sub>SO<sub>4</sub>.

#### SKILLBUILDER PLUS

Determine the number of each type of atom in Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>.

FOR MORE PRACTICE Example 5.18; Problems 33, 34, 35, 36.

#### **CONCEPTUAL CHECKPOINT 5.1**

Which of the following formulas represents the greatest number of atoms?

- (a)  $Al(C_2H_3O_2)_3$
- (b)  $Al_2(Cr_2O_7)_3$
- (c)  $Pb(HSO_4)_4$
- (d)  $Pb_3(PO_4)_4$
- (e)  $(NH_4)_3PO_4$

### 5.4

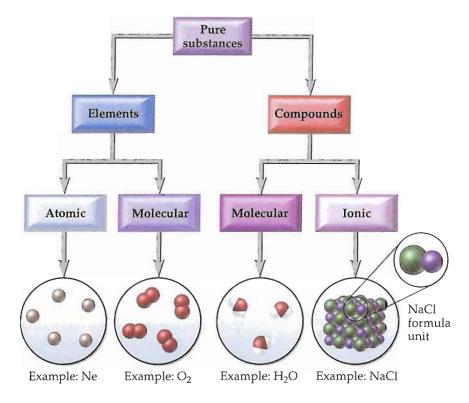
### A Molecular View of Elements and Compounds

In Chapter 3, we learned that pure substances could be divided into elements or compounds. We can further subdivide elements and compounds according to the basic units that compose them (▶ Figure 5.7). Pure substances may be elements, or they may be compounds. Elements may be either atomic or molecular. Compounds may be either molecular or ionic.

#### **ATOMIC ELEMENTS**

Atomic elements are those that exist in nature with single atoms as their basic units. Most elements fall into this category. For example, helium is composed of helium atoms, copper is composed of copper atoms, and mercury of mercury atoms (>> Figure 5.8).

Figure 5.7 A molecular view of elements and compounds



#### **MOLECULAR ELEMENTS**

**Molecular elements** do not normally exist in nature with single atoms as their basic units. Instead, these elements exist as *diatomic molecules*—two atoms of that element bonded together—as their basic units. For example, hydrogen is composed of  $H_2$  molecules, oxygen is composed of  $O_2$  molecules, and chlorine of  $Cl_2$  molecules ( $\triangledown$  Figure 5.9). Elements that exist as diatomic molecules are shown in Table 5.2 and in  $\triangleright$  Figure 5.10.

A few molecular elements, such as  $S_8$  and  $P_4$ , are composed of molecules containing several atoms.



◀ Figure 5.8 An atomic element The basic units that compose mercury, an atomic element and a metal, are single mercury atoms.



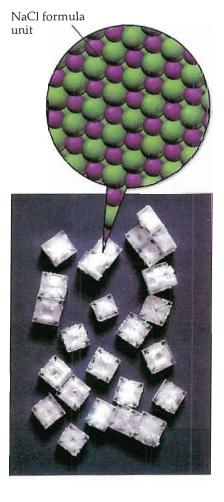
Figure 5.9 A molecular element The basic units that compose chlorine, a molecular element, are diatomic chlorine molecules, each composed of two chlorine atoms.

Figure 5.10 Elements that form diatomic molecules Elements that normally exist as diatomic molecules are highlighted in yellow on this periodic table. Note that six of the seven are nonmetals, including four of the halogens.

**TABLE 5.2** Elements That Occur as Diatomic Molecules

Name of Element	Formula of Basic Unit
hydrogen nitrogen oxygen	$H_2$ $N_2$ $O_2$
fluorine chlorine	F <sub>2</sub> Cl <sub>2</sub>
bromine iodine	$\operatorname{Br}_2$ $\operatorname{I}_2$

Remember that nonmetals occupy the upper right side of the periodic table.



	Main	groups													Main	groups	;	
,	1A 1	] <sub>2A</sub>	•						hat ex		S		3A	4A	5A	6A	7A	8A 18
	H	2	1										13	14	15	16	17	He
2	Li Li	Be				T	ransitio	n meta	nls				5 <b>B</b>	6 C	N	O	F	Ne
3	11 Na	Mg	3B 3	4B 4	5B 5	6B 6	7B 7	8	— 8B - 9		1B 11	2B 12	13 Al	14 Si	15 <b>P</b>	16 S	CI	18 <b>A</b> r
Periods &	19 <b>K</b>	<sup>20</sup> Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	<sup>26</sup> Fe	27 <b>Co</b>	28 Ni	<sup>29</sup> Cu	30 Zn	Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 <b>Y</b>	40 Zr	41 Nb	42 <b>M</b> o	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	<sup>54</sup> Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	<sup>76</sup> Os	77 Ir	78 Pt	79 <b>Au</b>	80 Hg	81 TI	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 <b>F</b> r	88 Ra	89 <b>Ac</b>	104 <b>Rf</b>	105 <b>Db</b>	106 Sg	107 <b>Bh</b>	108 Hs	109 <b>M</b> t	110 Ds	111 Rg	112	113	114	115	116		118
			Lantha	nides	58 Ce	59 <b>P</b> r	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 <b>Lu</b>
			Acti	nides	90 T <b>h</b>	91 <b>Pa</b>	92 <b>U</b>	93 <b>N</b> p	94 <b>Pu</b>	95 <b>Am</b>	96 Cm	97 <b>B</b> k	98 Cf	99 Es	100 <b>Fm</b>	101 <b>Md</b>	102 <b>No</b>	103 Lr

#### **MOLECULAR COMPOUNDS**

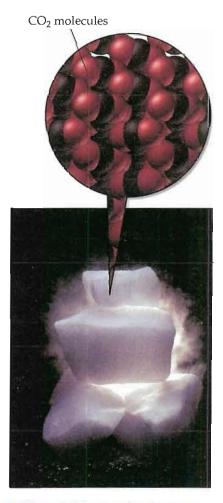
**Molecular compounds** are compounds formed from two or more nonmetals. The basic units of molecular compounds are molecules composed of the constituent atoms. For example, water is composed of  $H_2O$  molecules, dry ice is composed of  $CO_2$  molecules ( $\nabla$  Figure 5.11), and acetone (finger nail–polish remover) of  $C_3H_6O$  molecules.

#### IONIC COMPOUNDS

Ionic compounds are compounds formed from a metal and one or more nonmetals. When a metal, which has a tendency to lose electrons, combines with a nonmetal, which has a tendency to gain electrons, one or more electrons transfer from the metal to the nonmetal, creating positive and negative ions that are then attracted to each other. The basic unit of ionic compounds is the formula unit, the smallest electrically neutral collection of ions. Formula units are different from molecules in that they do not exist as discrete entities, but rather as part of a larger lattice. For example, salt (NaCl) is composed of Na+ and Cl ions in a 1:1 ratio. In table salt, Na<sup>+</sup> and Cl<sup>-</sup> ions exist in an alternating three-dimensional array ( Figure 5.12). However, any one Na<sup>+</sup> ion does not pair with one specific Cl ion. Sometimes chemists refer to formula units as molecules, but this is not strictly correct since ionic compounds do not contain distinct molecules.

#### Figure 5.12 An ionic compound

The basic units that compose table salt, an ionic compound, are NaCl formula units. Unlike molecular compounds, ionic compounds do not contain individual molecules but rather sodium and chloride ions in an alternating three-dimensional array.



▲ Figure 5.11 A molecular compound The basic units that compose dry ice, a molecular compound, are CO₂ molecules.

#### **EXAMPLE 5.4**

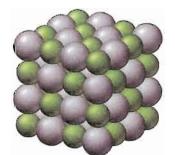
#### Classifying Substances as Atomic Elements, Molecular Elements, Molecular Compounds, or Ionic Compounds

Classify each of the following substances as an atomic element, molecular element, molecular compound, or ionic compound.

- (a) krypton
- **(b)** CoCl<sub>2</sub>
- (c) nitrogen
- (d) SO<sub>2</sub>
- (e)  $KNO_3$

#### Solution:

- (a) Krypton is an element that is not listed as diatomic in Table 5.2; therefore, it is an atomic element.
- (b) CoCl<sub>2</sub> is a compound composed of a metal (left side of periodic table) and nonmetal (right side of the periodic table); therefore, it is an ionic
- (c) Nitrogen is an element that is listed as diatomic in Table 5.2; therefore, it is a molecular element.
- (d) SO<sub>2</sub> is a compound composed of two nonmetals; therefore, it is a molecular compound.
- (e) KNO<sub>3</sub> is a compound composed of a metal and two nonmetals; therefore, it is an ionic compound.

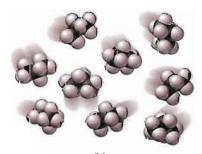


(a)

SKILLBUILDER 5.4 Classifying Substances as Atomic Elements, Molecular Elements, Molecular Compounds, or Ionic Compounds

Classify each of the following substances as an atomic element, molecular element, molecular compound, or ionic compound.

- (a) chlorine
- (b) NO
- (c) Au
- (d) Na<sub>2</sub>O
- (e) CrCl<sub>3</sub>



FOR MORE PRACTICE Example 5.19, Example 5.20; Problems 39, 40, 41, 42.

#### CONCEPTUAL CHECKPOINT 5.2

Which of the figures at left (in the margin) represents a molecular compound?

### Writing Formulas for Ionic Compounds

Review Section 4.7 and Figure 4.14 to learn the elements that form ions with a predictable charge.

Since ionic compounds must be charge-neutral, and since many elements form only one type of ion with a predictable charge, the formulas for many ionic compounds can be determined based on their constituent elements. For example, the formula for the ionic compound composed of sodium and chlorine must be NaCl and not anything else because in compounds Na always forms 1+ cations and Clalways forms 1- anions. In order for the compound to be charge-neutral, it must contain one Na<sup>+</sup> cation to every Cl<sup>-</sup> anion. The formula for the ionic compound composed of magnesium and chlorine, however, must be MgCl2, because Mg always forms 2+ cations and Cl

always forms 1— anions. In order for the compound to be charge-neutral, it must contain one Mg<sup>2+</sup> cation to every two Cl<sup>-</sup> anions. In general:

- Ionic compounds always contain positive and negative ions.
- In the chemical formula, the sum of the charges of the positive ions (cations) must always equal the sum of the charges of the negative ions (anions).

To write the formula for an ionic compound, follow the procedure in the left column below. Two examples of how to apply the procedure are provided in the center and right columns.

#### Writing Formulas **EXAMPLE 5.5 EXAMPLE 5.6** for Ionic Compounds Write a formula for the ionic com-Write a formula for the ionic compound that forms from aluminum pound that forms from magnesium and oxygen. and oxygen. Solution: Solution: 1. Write the symbol for the metal and its charge followed by the $Mg^{2+}$ $O^{2-}$ $Al^{3+} O^{2-}$ symbol of the nonmetal and its charge. For many elements, these charges can be determined from their group number in the periodic table (refer to Figure 4.14). 2. Make the magnitude of the charge on each ion (without the sign) become the subscript for the other ion. Reduce the subscripts to give a In this case, the numbers cannot be To reduce the subscripts, divide ratio with the smallest whole reduced any further; the correct both subscripts by 2. numbers. formula is $Al_2O_3$ . $Mg_2O_2 \div 2 = MgO$ Cations: 2(3+) = 6+Cations: 2+ 4. Check that the sum of the charges of the cations exactly cancels the Anions: 3(2-) = 6-Anions: 2sum of the charges of the anions. The charges cancel. The charges cancel. SKILLBUILDER 5.5 SKILLBUILDER 5.6 Write a formula for the compound Write a formula for the compound formed from cesium and oxygen. formed from aluminum and nitrogen. FOR MORE PRACTICE Example 5.21; Problems 49, 50, 51, 52.

### **EXAMPLE 5.7** Writing Formulas for Ionic Compounds

Write a formula for the compound that forms from potassium and oxygen.

#### Solution

We first write the symbol for each ion along with its appropriate charge from its group number in the periodic table.

$$K^{+}$$
  $O^{2-}$ 

We then make the magnitude of each ion's charge become the subscript for the other ion.

No reducing of subscripts is necessary in this case. Finally, we check to see that the sum of the charges of the cations [2(1+) = 2+] exactly cancels the sum of the charges of the anion (2-). The correct formula is  $K_2O$ .

#### SKILLBUILDER 5.7 Writing Formulas for Ionic Compounds

Write a formula for the compound that forms from calcium and bromine.

FOR MORE PRACTICE Problems 53, 54.

### 5.6 Nomenclature: Naming Compounds

Since there are so many different compounds, chemists have developed systematic ways to name them. If you learn these naming rules, you can simply examine a compound's formula to determine its name or vice versa. Many compounds, however, also have a common name. For example, H<sub>2</sub>O has the common name *water* and the systematic name *dihydrogen monoxide*. A common name is like a nickname for a compound, used by those who are familiar with it. Since water is such a familiar compound, everyone uses its common name and not its systematic name. In the sections that follow, we learn how to systematically name simple ionic and molecular compounds. Keep in mind, however, that some compounds also have common names that are often used instead of the systematic name. Common names can be learned only through familiarity.

### 5.7 Naming Ionic Compounds

The first step in naming an ionic compound is identifying it as one. Remember, *ionic compounds are formed from metals and nonmetals*; any time you see a metal and one or more nonmetals together in a chemical formula, it is an ionic compound. Ionic compounds can be divided into two types (\*\* Figure 5.13) depending on the metal in the compound. If the metal, in all of its different compounds, always forms a cation with the same charge, then the charge is implied and the compound is a **Type I compound**. Sodium, for instance, has a 1+ charge in all of its compounds and therefore forms Type I compounds. Some examples of Type I metals are listed in Table 5.3. The charge of most of these metals can be inferred from their group number in the periodic table (see Figure 4.14).

Figure 5.13 Classification of ionic compounds Ionic compounds can be divided into two types, depending on the metal in the compound. If the metal, in all of its compounds, always forms an ion with the same charge, it is a Type I ionic compounds, forms ions with different charges, it is a Type II ionic compound.

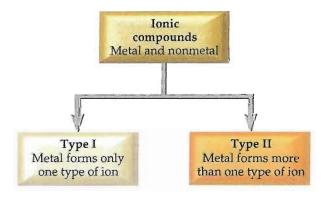
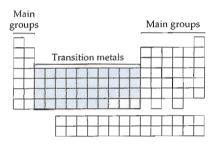


TABLE 5.3 Metals That Form Type I Ionic Compounds

Metal Ion		Name	Group Number	
Li	Li +	lithium	1A	
Na	Na <sup>+</sup>	sodium	1A	
K	K <sup>+</sup>	potassium	1A	
Rb	Rb <sup>+</sup>	rubidium	1A	
Cs	Cs <sup>+</sup>	cesium	1A	
Ве	Be <sup>2+</sup>	beryllium	2A	
Mg	Be <sup>2+</sup> Mg <sup>2+</sup> Ca <sup>2+</sup> Sr <sup>2+</sup>	magnesium	2A	
Ca	Ca <sup>2+</sup>	calcium	2A	
Sr	Sr <sup>2+</sup>	strontium	2A	
Ва	Ba <sup>2+</sup>	barium	2A	
Al	Al <sup>3+</sup>	aluminum	3A	
Zn	Zn <sup>2+</sup> Ag <sup>+</sup>	zinc	*	
Ag	Ag <sup>+</sup>	silver	*	

<sup>\*</sup>The charge of these metals cannot be inferred from their group number.

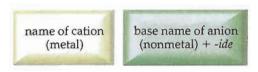


▲ Figure 5.14 The transition metals The elements that form Type II ionic compounds are usually transition metals.

If, on the other hand, the metal forms compounds in which its charge is not always the same, then the charge is not implied and the compound is a **Type II compound**. Iron, for instance, has a 2+ charge in some of its compounds and a 3+ charge in others. Such metals are usually found in the section of the periodic table known as the **transition metals** (4 Figure 5.14). (Some examples of metals that form Type II ionic compounds are shown in Table 5.4.)

#### NAMING TYPE I BINARY IONIC COMPOUNDS

**Binary compounds** are those containing only two different elements. The names for binary Type I ionic compounds have the following form:



**TABLE 5.4** Some Metals That Form Type II Ionic Compounds and Their Common Charges

Metal	Symbol Ion	Name	Older Name*
chromium	Cr <sup>2+</sup>	chromium(II)	chromous
	Cr <sup>3+</sup>	chromium(III)	chromic
iron	Fe <sup>2+</sup>	iron(II)	ferrous
	Fe <sup>3+</sup>	iron(III)	ferric
cobalt	Co <sup>2+</sup>	cobalt(II)	cobaltous
	Co <sup>3+</sup>	cobalt(III)	cobaltic
copper	Cu+	copper(I)	cuprous
	Cu <sup>2+</sup>	copper(II)	cupric
tin	Sn <sup>2+</sup>	tin(II)	stannous
	Sn <sup>4+</sup>	tin(IV)	stannic
mercury	$Hg_2^{2+}$	mercury(I)	mercurous
-	Hg2 <sup>2+</sup> Hg <sup>2+</sup>	mercury(II)	mercuric
lead	Pb <sup>2+</sup>	lead(II)	plumbous
	Pb <sup>4+</sup>	lead(IV)	plumbic

<sup>\*</sup>An older naming system substitutes the names found in this column for the name of the metal and its charge. Under this system, chromium(II) oxide is named chromous oxide. We will *not* use this older system in this text.

TABLE 5.5 Some Common Anions

Nonmetal	Symbol for Ion	Base Name	Anion Name
fluorine	F <sup>-</sup>	fluor-	fluoride
chlorine	Cl <sup>-</sup>	chlor-	chloride
bromine	Br <sup>-</sup>	brom-	bromide
iodine	I_	iod-	iodide
oxygen	$O^{2-}$	OX-	oxide
sulfur	S <sup>2-</sup>	sulf-	sulfide
nitrogen	$N^{3-}$	nitr-	nitride

For example, the name for NaCl consists of the name of the cation, sodium, followed by the base name of the anion, chlor, with the ending -ide. The full name is sodium chloride.

NaCl sodium chloride

The name for MgO consists of the name of the cation, *magnesium*, followed by the base name of the anion, *ox*, with the ending *-ide*. The full name is *magnesium oxide*.

MgO magnesium oxide

The base names for various nonmetals and their most common charges in ionic compounds are shown in Table 5.5.

#### EXAMPLE 5.8 Naming Type I Ionic Compounds

Give the name for the compound MgF<sub>2</sub>.

#### Solution:

The cation is magnesium. The anion is fluorine, which becomes *fluoride*. The correct name is *magnesium fluoride*.

#### SKILLBUILDER 5.8 Naming Type I Ionic Compounds

Give the name for the compound KBr.

#### SKILLBUILDER PLUS

Give the name for the compound  $Zn_3N_2$ .

FOR MORE PRACTICE Example 5.22; Problems 55, 56.

#### NAMING TYPE II BINARY IONIC COMPOUNDS

The names for binary (two-element) Type II ionic compounds have the following form:

name of cation (metal) in charge of cation (metal) in coman numerals in parentheses (nonmetal) + -ide

See Table 5.4 for some examples of metals that form Type II ionic compounds. The charge of the metal cation is obtained by interested from the sum of the charges of the nonmetal anions—remember that the sum of all the charges must be zero. For example, the name for FeCl<sub>3</sub> consists of the name

The name of the cation in ionic compounds is the same as the name of the metal.

of the cation, *iron*, followed by the charge of the cation in parentheses (*III*), followed by the base name of the anion, *chlor*, with the ending *-ide*. The full name is *iron*(*III*) *chloride*.

#### FeCl<sub>3</sub> iron(III) chloride

The charge of iron must be 3+ in order for the compound to be charge-neutral with three Cl<sup>-</sup> anions. Likewise, the name for CrO consists of the name of the cation, *chromium*, followed by the charge of the cation in parentheses (II), followed by the base name of the anion, ox-, with the ending -ide. The full name is chromium(II) oxide.

#### CrO chromium(II) oxide

The charge of chromium must be 2+ in order for the compound to be chargeneutral with one  $O^{2-}$  anion.

#### **EXAMPLE 5.9** Naming Type II Ionic Compounds

Give the name for the compound PbCl<sub>4</sub>.

#### Solution:

The name for  $PbCl_4$  consists of the name of the cation, *lead*, followed by the charge of the cation in parentheses (*IV*), followed by the base name of the anion, *chlor-*, with the ending *-ide*. The full name is lead(IV) *chloride*. We know the charge on Pb is 4+ because the charge on Cl is 1-. Since there are  $4 Cl^-$  anions, the Pb cation must be  $Pb^{4+}$ .

PbCl<sub>4</sub> lead(IV) chloride

#### SKILLBUILDER 5.9 Naming Type II Ionic Compounds

Give the name for the compound PbO.

FOR MORE PRACTICE Example 5.23; Problems 57, 58.

# NAMING IONIC COMPOUNDS CONTAINING A POLYATOMIC ION

Some ionic compounds contain ions that are themselves composed of a group of atoms with an overall charge. These ions are called **polyatomic ions** and are shown in Table 5.6. Ionic compounds containing polyatomic ions are

TABLE 5.6 Some Common Polyatomic lons

Name	Formula	Name	Formula	
acetate	$C_2H_3O_2^-$	hypochlorite	CIO-	
carbonate	$CO_3^{2-}$	chlorite	ClO <sub>2</sub>	
hydrogen carbonate (or bicarbonate)	HCO <sub>3</sub> -	chlorate	ClO <sub>3</sub>	
hydroxide	OH-	perchlorate	$ClO_4^-$	
nitrate	$NO_3^-$	permanganate	$MnO_4^-$	
nitrite	NO <sub>2</sub> -	sulfate	$SO_4^{2-}$	
chromate	CrO <sub>4</sub> <sup>2-</sup>	sulfite	$SO_3^{2-}$	
dichromate	$Cr_2O_7^{2-}$	hydrogen sulfite (or bisulfite)	HSO <sub>3</sub> -	
phosphate	PO <sub>4</sub> 3-	hydrogen sulfate (or bisulfate)	$HSO_4^-$	
hydrogen phosphate	HPO <sub>4</sub> <sup>2-</sup>	peroxide	$O_2^{2^{-}}$	
ammonium	$NH_4^+$	cyanide	CN-	

named using the same procedure we apply to other ionic compounds, except that the name of the polyatomic ion is used whenever it occurs. For example,  $KNO_3$  is named according to its cation,  $K^+$ , potassium, and its polyatomic anion,  $NO_3^-$ , nitrate. The full name is potassium nitrate.

#### KNO<sub>3</sub> potassium nitrate

Fe(OH)<sub>2</sub> is named according to its cation, *iron*, its charge (II), and its polyatomic ion, *hydroxide*. The full name is *iron*(II) *hydroxide*.

If the compound contains both a polyatomic cation and a polyatomic anion, simply use the names of both polyatomic ions. For example, NH<sub>4</sub>NO<sub>3</sub> is named *ammonium nitrate*.

#### NH<sub>4</sub>NO<sub>3</sub> ammonium nitrate

You must be able to recognize polyatomic ions in a chemical formula, so become familiar with Table 5.6. Most polyatomic ions are **oxyanions**, anions containing oxygen. Notice that when a series of oxyanions contain different numbers of oxygen atoms, they are named systematically according to the number of oxygen atoms in the ion. If there are two ions in the series, the one with more oxygen atoms is given the ending *-ate* and the one with fewer is given the ending *-ite*. For example, NO<sub>3</sub><sup>-</sup> is called *nitrate* and NO<sub>2</sub><sup>-</sup> is called *nitrite*.

NO<sub>3</sub> nitrate NO<sub>2</sub> nitrite

If there are more than two ions in the series, then the prefixes hypo-, meaning "less than," and per-, meaning "more than," are used. So ClO $^-$  is called hypochlorite, meaning "less oxygen than chlorite," and ClO $_4$  $^-$  is called perchlorate, meaning "more oxygen than chlorate."

 $ClO^-$  hypochlorite  $ClO_2^-$  chlorite  $ClO_3^-$  chlorate  $ClO_4^-$  perchlorate

### **EXAMPLE 5.10** Naming Ionic Compounds That Contain a Polyatomic Ion

Give the name for the compound K<sub>2</sub>CrO<sub>4</sub>.

#### Solution:

The name for  $K_2CrO_4$  consists of the name of the cation, *potassium*, followed by the name of the polyatomic ion, *chromate*.

K<sub>2</sub>CrO<sub>4</sub> potassium chromate

### SKILLBUILDER 5.10 Naming Ionic Compounds That Contain a Polyatomic Ion

Give the name for the compound  $Mn(NO_3)_2$ .

FOR MORE PRACTICE Example 5.24; Problems 61, 62.

# **Everyday Chemistry**

### **Polyatomic Ions**

A glance at the labels of household products reveals the importance of polyatomic ions in everyday compounds. For example, the active ingredient in household bleach is sodium hypochlorite, which acts to destroy color-causing molecules in clothes (bleaching action) and to kill bacteria (disinfection). A box of baking soda contains sodium bicarbonate (sodium hydrogen carbonate), which acts as an antacid when consumed in small amounts and also as a source of carbon dioxide gas in baking. The pockets of carbon dioxide gas make baked goods fluffy rather than flat.



Calcium carbonate is the active ingredient in many antacids such as Tums<sup>TM</sup> and Alka-Mints<sup>TM</sup>. It neutralizes stomach acids, relieving the symptoms of indigestion and heartburn. Too much calcium carbonate, however, can cause constipation, so Tums should not be overused. Sodium nitrite is a common food additive used to preserve packaged meats such as ham, hot dogs, and bologna. Sodium nitrite inhibits the growth of bacteria, especially those that cause botulism, an often fatal type of food poisoning.

**CAN YOU ANSWER THIS?** Write a formula for each of these compounds that contain polyatomic ions: sodium hypochlorite, sodium bicarbonate, calcium carbonate, sodium nitrite.



▲ The active ingredient in bleach is sodium hypochlorite.

Compounds containing polyatomic ions are present in many consumer products.

### 5.8 Naming Molecular Compounds

The first step in naming a molecular compound is identifying it as one. Remember, molecular compounds form from two or more nonmetals. In this section, we learn how to name binary (two-element) molecular compounds. Their names have the following form:



When writing the name of a molecular compound, as when writing the formula, the first element is the more metal-like one (see Table 5.1). The prefixes given to each element indicate the number of atoms present.

топо- 1	penta- 5
di- 2	hexa- 6
tri- 3	hepta- 7
tetra- 4	octa- 8

If there is only one atom of the *first element* in the formula, the prefix *mono*- is normally omitted. For example,  $CO_2$  is named according to the first element, *carbon*, with no prefix because *mono*- is omitted for the first element, followed by the prefix di-, to indicate two oxygen atoms, followed by the base name of the second element, ox, with the ending *-ide*.

carbon di- ox -ide

The full name is carbon dioxide.

CO<sub>2</sub> carbon dioxide

The compound  $N_2O$ , also called laughing gas, is named according to the first element, *nitrogen*, with the prefix di-, to indicate that there are two of them, followed by the base name of the second element, ox, prefixed by mono-, to indicate one, and the suffix -ide. Since mono- ends with a vowel and oxide begins with one, an o is dropped and the two are combined as monoxide. The entire name is  $dinitrogen\ monoxide$ .

N<sub>2</sub>O dinitrogen monoxide

#### **EXAMPLE 5.11** Naming Molecular Compounds

Name each of the following: CCl<sub>4</sub>, BCl<sub>3</sub>, SF<sub>6</sub>.

#### Solution:

CCl<sub>4</sub>

The name of the compound is the name of the first element, *carbon*, followed by the base name of the second element, *chlor*, prefixed by *tetra*- to indicate four, and the suffix *-ide*. The entire name is *carbon tetrachloride*.

BCl<sub>3</sub>

The name of the compound is the name of the first element, *boron*, followed by the base name of the second element, *chlor*, prefixed by *tri-* to indicate three, and the suffix *-ide*. The entire name is *boron trichloride*.

 $SF_6$ 

The name of the compound is the name of the first element, *sulfur*, followed by the base name of the second element, *fluor*, prefixed by *hexa-* to indicate six, and the suffix *-ide*. The entire name is *sulfur hexafluoride*.

#### SKILLBUILDER 5.11 Naming Molecular Compounds

Name the compound  $N_2O_4$ .

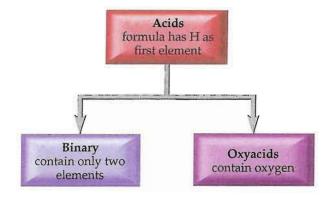
FOR MORE PRACTICE Example 5.25; Problems 67, 68.

### 5.9 Naming Acids

Acids are molecular compounds that form  $H^+$  ions when dissolved in water. They are composed of hydrogen, usually written first in their formula, and one or more nonmetals, written second. Acids are characterized by their sour taste and their ability to dissolve some metals. For example, HCl(aq) is an acid—the (aq) means "aqueous" or "dissolved in water"; that is, it is a molecular compound that forms  $H^+$  ions in water. HCl(aq) has a characteristically

When the prefix ends with a vowel and the base name starts with a vowel, the first vowel is sometimes dropped, especially in the case of mono oxide, which becomes monoxide.

Figure 5.15 Classification of acids Acids can be divided into two types, depending on the number of elements in the acid. If the acid contains only two elements, it is a binary acid. If it contains oxygen, it is an oxyacid.



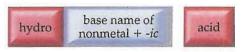
HCI(g) refers to HCI molecules in the gas phase.

sour taste. Since HCl(aq) is present in stomach fluids, its sour taste becomes painfully obvious during vomiting. HCl(aq) also dissolves some metals. For example, if you drop a strip of zinc into a beaker of HCl(aq), it will slowly disappear as the acid converts the zinc metal into dissolved  $Zn^{2+}$  cations.

Acids are present in many foods, such as lemons and limes, and they are used in some household products such as toilet bowl cleaner and Lime-A-Way. In this section, we simply learn how to name them, but in Chapter 14 we will learn more about their properties. Acids can be divided into two categories: binary acids, those containing only hydrogen and a nonmetal, and oxyacids, those containing hydrogen, a nonmetal, and oxygen (A Figure 5.15).

#### **NAMING BINARY ACIDS**

Binary acids are composed of hydrogen and a nonmetal. The names for binary acids have the following form:



For example, HCl(aq) is named hydrochloric acid and HBr(aq) is named hydrobromic acid.

HCl(aq) hydrochloric acid

HBr(aq) hydrobromic acid

#### EXAMPLE 5.12 Naming Binary Acids

Give the name of  $H_2S(aq)$ .

The base name of S is *sulfur*, so the name is *hydrosulfuric acid*.

Solution:

 $H_2S(aq)$  hydrosulfuric acid

#### SKILLBUILDER 5.12 Naming Binary Acids

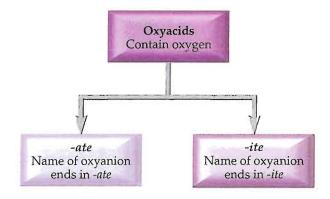
Give the name of HF(aq).

FOR MORE PRACTICE Example 5.26; Problems 73b, 74d.

#### NAMING OXYACIDS

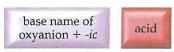
Oxyacids are derived from the oxyanions found in the table of polyatomic ions (Table 5.6). For example,  $HNO_3(aq)$  is derived from the nitrate ( $NO_3^-$ ) ion,  $H_2SO_3(aq)$  is derived from the sulfite ( $SO_3^{2-}$ ) ion, and  $H_2SO_4(aq)$  is derived from the sulfate ( $SO_4^{2-}$ ) ion. Notice that these acids are simply a combination of one or more  $H^+$  ions with an oxyanion. The number of  $H^+$  ions

Figure 5.16 Classification of oxyacids Oxyacids can be divided into two types, depending on the ending of the oxyanion from which they are derived.

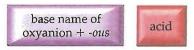


depends on the charge of the oxyanion, so that the formula is always charge-neutral. The names of oxyacids depend on the ending of the oxyanion ( $\triangle$  Figure 5.16).

The names of acids composed of oxyanions ending with -ate have the following form:



The names of acids composed of oxyanions ending with -ite take this form:



So  $HNO_3$  is named *nitric acid* (oxyanion is nitrate), and  $H_2SO_3$  is named *sulfurous acid* (oxyanion is sulfite).

HNO<sub>3</sub>(aq) nitric acid

H<sub>2</sub>SO<sub>3</sub>(aq) sulfurous acid

#### EXAMPLE 5.13 Naming Oxyacids

Give the name of  $HC_2H_3O_2(aq)$ .

The oxyanion is acetate, which ends in -ate; therefore, the name of the acid is acetic acid.

Solution:

 $HC_2H_3O_2(aq)$  acetic acid

#### SKILLBUILDER 5.13 Naming Oxyacids

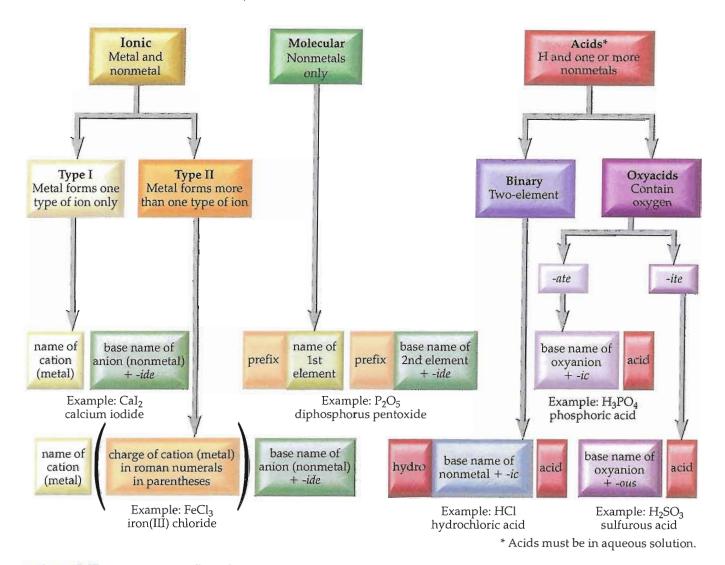
Give the name of  $HNO_2(aq)$ .

FOR MORE PRACTICE Example 5.27, Example 5.28; Problems 73acd, 74abc.

### 5.10 Nomenclature Summary

Acids are technically a subclass of molecular compounds; that is, they are molecular compounds that form H<sup>+</sup> ions when dissolved in water.

Naming compounds requires several steps. The flow chart in Figure 5.17 summarizes the different categories of compounds that we have learned and how to identify and name them. The first step is to decide whether the compound is ionic, molecular, or an acid. You can recognize ionic compounds by the presence of a metal and a nonmetal, molecular compounds by two or more nonmetals, and acids by the presence of hydrogen (written first) and one or more nonmetals.



▲ Figure 5.17 Nomenclature flow chart

Zinc (Zn<sup>2+</sup>), scandium (Sc<sup>3+</sup>,) and silver (Ag<sup>+</sup>) also from Type I ionic compounds.

#### IONIC COMPOUNDS

For an ionic compound, you must next decide whether it is a Type I or Type II ionic compound. Group 1A (alkali) metals, Group 2A (alkaline earth) metals, and aluminum will always form Type I ionic compounds (Figure 4.14). Most of the transition metals will form Type II ionic compounds. Once you have identified the type of ionic compound, name it according to the scheme in the chart. If the ionic compound contains a polyatomic ion—something you must recognize by familiarity—insert the name of the polyatomic ion in place of the metal (positive polyatomic ion) or the nonmetal (negative polyatomic ion).

#### **MOLECULAR COMPOUNDS**

We have learned how to name only one type of molecular compound, the binary (two-element) compound. If you identify a compound as molecular, name it according to the scheme in Figure 5.17.

# Chemistry in the Environment

#### **Acid Rain**

Acid rain occurs when rainwater mixes with air pollutants—such as NO, NO<sub>2</sub>, and SO<sub>2</sub>—that form acids. NO and NO<sub>2</sub>, primarily from vehicular emission, combine with water to form HNO<sub>3</sub>(aq). SO<sub>2</sub>, primarily from coal-powered electricity generation, combines with water and oxygen in air to form H<sub>2</sub>SO<sub>4</sub>(aq). HNO<sub>3</sub>(aq) and H<sub>2</sub>SO<sub>4</sub>(aq) both cause rainwater to become acidic. The problem is greatest in the northeastern United States, where pollutants from midwestern electrical power plants combine with rainwater to produce rain with acid levels that are up to ten times higher than normal.

When acid rain falls or flows into lakes and streams, it makes them more acidic. Some species of aquatic animals—such as trout, bass, snails, salamanders, and clams—cannot tolerate the increased acidity and die. This then disturbs the ecosystem of the lake, resulting in imbalances that may lead to the death of other aquatic species. Acid rain also weakens trees by dissolving nutrients in the soil and by damaging their leaves. Appalachian red spruce trees have been the hardest hit, with many forests showing significant acid rain damage.

Acid rain also damages building materials. Acids dissolve CaCO<sub>3</sub> (limestone), a main component of marble



👗 A forest damaged by acid rain.



Acid rain harms many materials, including the limestone often used for tombstones, buildings, and statues.

and concrete, and iron, the main component of steel. Consequently, many statues, buildings, and bridges in the northeastern United States show significant deterioration, and some historical gravestones made of limestone are barely legible due to acid rain damage.

Although acid rain has been a problem for many years, innovative legislation has offered hope for change. In 1990, Congress passed several amendments to the Clean Air Act that included provisions requiring electrical utilities to reduce SO<sub>2</sub> emissions. Since then, SO<sub>2</sub> emissions have decreased, and rain in the northeastern United States has become somewhat less acidic. With time, and continued enforcement of the acid rain program, lakes, streams, and forests damaged by acid rain should recover. However, acid rain continues to worsen in countries such as China, where industrial growth is outpacing environmental controls. International cooperation is essential to solving environmental problems such as acid rain.

**CAN YOU ANSWER THIS?** Provide the names for each of the following compounds, given here as formulas:

NO, NO<sub>2</sub>, SO<sub>2</sub>, HNO<sub>3</sub>(aq), CaCO<sub>3</sub>

#### ACIDS

To name an acid, you must first decide whether it is a binary (two-element) acid or an oxyacid (an acid containing oxygen). Binary acids are named according to the scheme in Figure 5.17. Oxyacids must be further subdivided based on the name of their corresponding oxyanion. If the oxyanion ends in *-ate*, use one scheme; if it ends with *-ite*, use the other.

#### EXAMPLE 5.14 Nomenclature Using Figure 5.17

Name each of the following: CO,  $CaF_2$ , HF(aq),  $Fe(NO_3)_3$ ,  $HClO_4(aq)$ ,  $H_2SO_3(aq)$ .

#### Solution:

For each compound, the following table shows how to use Figure 5.17 to arrive at a name for the compound.

Formula	Flow Chart Path	Name
CO	Molecular	carbon monoxide
CaF <sub>2</sub>	Ionic $\longrightarrow$ Type I $\longrightarrow$	calcium fluoride
HF(aq)	Acid → Binary →	hydrofluoric acid
$Fe(NO_3)_3$	Ionic $\longrightarrow$ Type II $\longrightarrow$	iron(III) nitrate
$HClO_4(aq)$	Acid $\longrightarrow$ Oxyacid $\longrightarrow$ -ate $\longrightarrow$	perchloric acid
$H_2SO_3(aq)$	Acid $\longrightarrow$ Oxyacid $\longrightarrow$ -ite $\longrightarrow$	sulfurous acid

FOR MORE PRACTICE Problems 87, 88.

### 5.11 Formula Mass: The Mass of a Molecule or Formula Unit

Also in common use are the terms molecular mass and molecular weight, which have the same meaning as formula mass.

Chapter 4 introduced atoms and elements and designated the average mass of the atoms that compose an element as the atomic mass for that element. Similarly, in this chapter, which introduces molecules and compounds, we designate the average mass of the molecules (or formula units) that compose a compound as the **formula mass**.

For any compound, the formula mass is simply the sum of the atomic masses of all the atoms in its chemical formula:

Like atomic mass for atoms, formula mass characterizes the average mass of a molecule or formula unit. For example, the formula mass of water,  $H_2O$ , is:

Formula mass = 
$$2(1.01 \text{ amu}) + 16.00 \text{ amu}$$
  
=  $18.02 \text{ amu}$ 

and that of sodium chloride, NaCl, is:

Formula mass = 
$$22.99$$
 amu +  $35.45$  amu =  $58.44$  amu

In addition to giving a characteristic mass to the molecules or formula units of a compound, formula mass—as we will learn in Chapter 6—allows us to quantify the number of molecules or formula units in a sample of a given mass.

#### EXAMPLE 5.15 Calculating Formula Mass

Calculate the formula mass of carbon tetrachloride, CCl<sub>4</sub>.

#### Solution:

To find the formula mass, we sum the atomic masses of each atom in the chemical formula.

Formula mass =  $1 \times (Formula mass C) + 4 \times (Formula mass Cl)$ 

= 12.01 amu + 4(35.45 amu)

= 12.01 amu + 141.80 amu

 $= 153.8 \, \text{amu}$ 

#### SKILLBUILDER 5.15 Calculating Formula Masses

Calculate the formula mass of dinitrogen monoxide, N2O, also called laughing gas.

FOR MORE PRACTICE Example 5.29; Problems 77, 78.

#### **CONCEPTUAL CHECKPOINT 5.3**

Which of the following has the greatest formula mass?

- (a)  $O_2$
- (b)  $O_3$
- (c) H<sub>2</sub>O
- (d)  $H_2O_2$

# **Chapter in Review**

### Chemical Principles

#### Compounds: Matter is ultimately composed of atoms, but those atoms are often combined in compounds. The most important characteristic of a compound is its constant composition. The elements that compose a particular compound are in fixed, definite proportions in all samples of the compound.

Chemical Formulas: Compounds are represented by chemical formulas, which indicate the elements present in the compound and the relative number of atoms of each. These formulas represent the basic units that compose a compound.

Pure substances can be categorized according to the basic units that compose them. Elements can be composed of atoms or molecules. Compounds can be molecular, in which case their basic units are molecules, or ionic, in which case their basic units are ions. The formulas for many ionic compounds can be written simply by knowing the elements in the compound.

#### Relevance

Compounds: Most of the matter we encounter is in the form of compounds. Water, salt, and carbon dioxide are all good examples of common simple compounds. More complex compounds include caffeine, aspirin, acetone, and testosterone.

**Chemical Formulas:** To understand compounds, we must understand their composition, which is represented by a chemical formula. The connection between the microscopic world and the macroscopic world hinges on the particles that compose matter. Since most matter is in the form of compounds, the properties of most matter depend on the molecules or ions that compose it. Molecular matter does what its molecules do; ionic matter does what its ions do. The world we see and experience is governed by what these particles are doing.

### **Chemical Principles**

**Chemical Nomenclature:** The names of simple ionic compounds, molecular compounds, and acids can all be written by examining their chemical formula. The nomenclature flow chart (Figure 5.17) shows the basic procedure for determining these names.

**Formula Mass:** The formula mass of a compound is the sum of the atomic masses of all the atoms in the chemical formula for the compound. Like atomic mass for elements, formula mass characterizes the average mass of a molecule or formula unit.

#### Relevance

**Chemical Nomenclature:** Since there are so many compounds, we need a systematic way to name them. By learning these few simple rules, you will be able to name thousands of different compounds. The next time you look at the label on a consumer product, try to identify as many of the compounds as you can.

**Formula Mass:** Besides being the characteristic mass of a molecule or formula unit, formula mass is important in many calculations involving the composition of compounds and quantities in chemical reactions.

#### **Chemical Skills**

### Constant Composition of Compounds (Section 5.2)

The law of constant composition states that all samples of a given compound should have the same ratio of their constituent elements.

To determine whether experimental data is consistent with the law of constant composition, compute the ratios of the masses of each element in all samples. When computing these ratios, it is most convenient to put the larger number in the numerator (top) and the smaller one in the denominator (bottom); that way, the ratio is greater than 1. If the ratios are the same, then the data is consistent with the law of constant composition.

#### Examples

### EXAMPLE 5.16 Constant Composition of Compounds

Two samples said to be carbon disulfide ( $CS_2$ ) are decomposed into their constituent elements. One sample produced 8.08 g S and 1.51 g C, while the other produced 31.3 g S and 3.85 g C. Are these results consistent with the law of constant composition?

Solution: Sample 1

$$\frac{\text{Mass S}}{\text{Mass C}} = \frac{8.08 \text{ g}}{1.51 \text{ g}} = 5.35$$

Sample 2

$$\frac{\text{Mass S}}{\text{Mass C}} = \frac{31.3 \text{ g}}{3.85 \text{ g}} = 8.13$$

These results are not consistent with the law of constant composition so the information that the two samples are the same substance must therefore be in error.

#### Writing Chemical Formulas (Section 5.3)

Chemical formulas indicate the elements present in a compound and the relative number of atoms of each. When writing formulas, put the more metallic element first.

#### **EXAMPLE 5.17 Writing Chemical Formulas**

Write a chemical formula for the compound containing one nitrogen atom for every two oxygen atoms.

#### Solution:

 $NO_2$ 

#### Total Number of Each Type of Atom in a Chemical Formula (Section 5.3)

The numbers of atoms not enclosed in parentheses are given directly by their subscript.

The numbers of atoms within parentheses are found by multiplying their subscript within the parentheses by their subscript outside the parentheses.

# Classifying Elements as Atomic or Molecular (Section 5.4)

Most elements exist as atomic elements, their basic units in nature being individual atoms. However, several elements ( $H_2$ ,  $N_2$ ,  $O_2$ ,  $F_2$ ,  $Cl_2$ ,  $Br_2$ , and  $I_2$ ) exist as molecular elements, their basic units in nature being diatomic molecules.

# Classifying Compounds as Ionic or Molecular (Section 5.4)

Compounds containing a metal and a nonmetal are ionic. Metals that form *more than one* type of ion, typical of transition metals, are Type II.

Compounds containing a metal and one or more nonmetals are ionic. Metals that form one type of ion—typical of Group I, Group II, and aluminum—are Type I.

Compounds composed of nonmetals are molecular.

# Writing Formulas for Ionic Compounds (Section 5.5)

- 1. Write the symbol for the metal ion followed by the symbol for the nonmetal ion (or polyatomic ion) and their charges. These charges can be deduced from the group numbers in the periodic table. (In the case of polyatomic ions, the charges come from Table 5.6.)
- 2. Make the magnitude of the charge on each ion become the subscript for the other ion.
- 3. Check to see if the subscripts can be reduced to simpler whole numbers. Subscripts of 1 can be dropped, since they are normally implied.
- 4. Check that the sum of the charges of the cations exactly cancels the sum of the charges of the anions.

#### **EXAMPLE 5.18**

# Total Number of Each Type of Atom in a Chemical Formula

Determine the number of each type of atom in  $Pb(ClO_3)_2$ .

#### Solution:

One Pb atom

Two Cl atoms Six O atoms

#### **EXAMPLE 5.19**

### Classifying Elements as Atomic or Molecular

Classify each of the following elements as atomic or molecular: Na, I, N.

#### Solution:

Na: atomic

I: molecular (I<sub>2</sub>)

N: molecular  $(N_2)$ 

#### EXAMPLE 5.20

### Classifying Compounds as Ionic or Molecular

Classify each of the following compounds as ionic or molecular. If they are ionic, classify them as Type I or Type II ionic compounds:

#### Solution:

FeCl<sub>3</sub>: ionic, Type II

K<sub>2</sub>SO<sub>4</sub>: ionic, Type I

CCl<sub>4</sub>: molecular

#### EXAMPLE 5.21

# Writing Formulas for Ionic Compounds

Write a formula for the compound that forms from lithium and sulfate ions.

#### Solution:

$$Li^+$$
  $SO_4^{2-}$ 

In this case, the subscripts cannot be further reduced.

Cations: Anions:

$$2(1+) = 2+ 2-$$

#### Naming Type I Binary Ionic Compounds (Section 5.7)

The name of the metal is unchanged. The name of the nonmetal is its base name with the ending -ide.

### **EXAMPLE 5.22**

#### Naming Type I Binary Ionic Compounds

Give the name for the compound  $Al_2O_3$ .

#### Solution:

aluminum oxide

#### Naming Type II Binary Ionic Compounds (Section 5.7)

Since the name of Type II compounds includes the charge of the metal ion, we must first find that charge. To do this, compute the total charge of the nonmetal ions.

The total charge of the metal ions must equal the total charge of the nonmetal ions, but have the opposite sign.

The name of the compound is the name of the metal ion, followed by the charge of the metal ion, followed by the base name of the nonmetal + -ide.

### Naming Compounds Containing a Polyatomic

Name Type I and Type II ionic compounds containing a polyatomic ion in the normal way, except substitute the name of the polyatomic ion (from Table 5.6) in place of the nonmetal. (This example is Type II.)

Ion (Section 5.7)

The charge on the metal ion must be equal in magnitude to the sum of the charges of the polyatomic ions but opposite in sign.

The name of the compound is the name of the metal ion, followed by the charge of the metal ion, followed by the name of the polyatomic ion.

#### **EXAMPLE 5.23**

#### Naming Type II Binary Ionic Compounds

Give the name for the compound Fe<sub>2</sub>S<sub>3</sub>.

#### Solution:

3 sulfide ions 
$$\times$$
 (2-) = 6-

2 iron ions 
$$\times$$
 (?) = 6+

Charge of each iron ion = 3+

iron(III) sulfide

#### **EXAMPLE 5.24**

#### Naming Compounds Containing a Polyatomic Ion

Give the name for the compound  $Co(ClO_4)_2$ .

#### Solution:

2 perchlorate ions  $\times$  (1-) = 2-Charge of cobalt ion = 2+

cobalt(II) perchlorate

#### Naming Molecular Compounds (Section 5.8)

The name consists of a prefix indicating the number of atoms of the first element, followed by the name of the first element, and a prefix for the number of atoms of the second element followed by the base name of the second element plus the suffix -ide. When mono- occurs on the first element, it is normally dropped.

#### EXAMPLE 5.25 Naming Molecular Compounds

Name the compound NO<sub>2</sub>.

#### Solution:

nitrogen dioxide

#### Naming Binary Acids (Section 5.9)

The name begins with hydro-, followed by the base name of the nonmetal, plus the suffix -ic and then the word acid.

#### EXAMPLE 5.26 Naming Binary Acids

Name the acid HI(aq).

#### Solution:

hydroiodic acid

#### Naming Oxyacids with an Oxyanion Ending in -ate (Section 5.9)

The name is the base name of the oxyanion + -ic, followed by the word acid (sulfate violates the rule somewhat, since in strict terms, the base name would be *sulf*).

### **EXAMPLE 5.27**

Naming Oxyacids with an Oxyanion Ending in -ate

Name the acid  $H_2SO_4(aq)$ .

#### Solution:

The oxyanion is sulfate. The name of the acid is sulfuric acid.

#### Naming Oxyacids with an Oxyanion Ending in -ite (Section 5.9)

The name is the base name of the oxyanion + -ous, followed by the word acid.

#### **EXAMPLE 5.28**

Naming Oxyacids with an Oxyanion Ending in -ite

Name the acid  $HClO_2(aq)$ .

#### Solution:

The oxyanion is chlorite. The name of the acid is chlorous acid.

#### Calculating Formula Mass (Section 5.11)

The formula mass is the sum of the atomic masses of all the atoms in the chemical formula. In determining the number of each type of atom, don't forget to multiply subscripts inside parentheses by subscripts outside parentheses.

**EXAMPLE 5.29 Calculating Formula Mass** 

Calculate the formula mass of  $Mg(NO_3)_2$ .

#### Solution:

Formula mass = 24.31 + 2(14.01) + 6(16.00)= 148.33 amu

#### KEY TERMS

acid [5.9] atomic element [5.4] binary acid [5.9] binary compound [5.7] chemical formula [5.3]

formula mass [5.11] formula unit [5.4] ionic compound [5.4] law of constant composition [5.2]

molecular compound [5.4] molecular element [5.4] oxyacid [5.9] oxyanion [5.7] polyatomic ion [5.7]

transition metals [5.7] Type I compound [5.7] Type II compound [5.7]

### **EXERCISES**

#### Questions

- 1. Do the properties of an element change when it combines with another element to form a compound? Explain.
- 2. How would the world be different if elements did not combine to form compounds?
- 3. What is the law of constant composition? Who dis-
- **4.** What is a chemical formula? Give some examples.
- 5. In a chemical formula, which element is listed first?
- 6. In a chemical formula, how do you calculate the number of atoms of an element within parentheses? Give an example.
- 7. What is the difference between a molecular element and an atomic element? List the elements that occur as diatomic molecules.

- 8. What is the difference between an ionic compound and a molecular compound?
- 9. What is the difference between a common name for a compound and a systematic name?
- **10.** List the metals that form Type I ionic compounds. What are the group numbers of these metals?
- 11. Find the block in the periodic table of elements that tend to form Type II ionic compounds. What is the name of this block?
- 12. What is the basic form for the names of Type I ionic compounds?
- 13. What is the basic form for the names of Type II ionic compounds?
- 14. Why are numbers needed in the names of Type II ionic compounds?