



CHAPTER 6

MORE ON CHEMICAL COMPOUNDS

Please excuse Lisa for being absent; she was sick and I had her shot.

A note to the teacher to explain why a child was absent

We can probably assume that the parent who wrote this note meant the child was taken to the doctor for an injection, but who knows? Like everyone else, chemists need to be careful about how they use language, and the names and formulas for chemical compounds form the core of the language of chemistry. One of the goals of this chapter is to describe how you convert between the names and chemical formulas for many chemical compounds.

Before you learn to convert between names and formulas of acids, Section 6.3 describes what acids are. Acids have many uses. For example, phosphoric acid is used to make gasoline additives and carbonated beverages. The textile industry uses oxalic acid (found in rhubarb and spinach) to bleach cloth, and glass is etched by hydrofluoric acid. Dyes and many other chemicals are made with sulfuric acid and nitric acid, and corn syrup, which is added to a variety of foods, is processed with hydrochloric acid.

The last three sections of this chapter expand on the information found in Section 3.6, which showed you how you can convert between the measurable property of mass and the number of moles of atoms in a sample of an element. Section 6.6 shows you how you can do similar calculations for compounds, and Sections 6.7 and 6.8 show ways that these calculations can be used.



- 6.1 Ionic Nomenclature
- 6.2 Binary Covalent Nomenclature
- 6.3 Acids
- 6.4 Acid Nomenclature
- 6.5 Summary of Chemical Nomenclature
- 6.6 Molar Mass and Chemical Compounds
- 6.7 Relationships Between Masses of Elements and Compounds
- 6.8 Determination of Empirical and Molecular Formulas

Review Skills

The presentation of information in this chapter assumes that you can already perform the tasks listed below. You can test your readiness to proceed by answering the Review Questions at the end of the chapter. This might also be a good time to read the Chapter Objectives, which precede the Review Questions.

- Given an atomic mass for an element, write a conversion factor that converts between mass and moles of that element. (Section 3.6)
- Given a periodic table that shows atomic masses of the elements, convert between mass of an element and moles of that element. (Section 3.6)
- Given a formula for a compound, classify it as either a molecular compound or an ionic compound. (Section 5.2)
- Predict charges on monatomic ions. (Section 5.3)
- Write the definitions for monatomic anion, monatomic cation, and polyatomic ion. (Chapter 5 glossary)

6.1 Ionic Nomenclature

The naming of chemical compounds is often called chemical nomenclature. We start our exploration of chemical nomenclature and the development of our ability to convert between names and formulas with ionic compounds.

Naming Monatomic Anions and Cations

OBJECTIVE 2

Monatomic anions are named by adding -ide to the root of the name of the nonmetal that forms the anion. For example, N^{3-} is the nitride ion. The roots of the nonmetallic atoms are listed in Table 6.1, and the names of the anions are displayed in Table 6.2.

OBJECTIVE 3

Table 6.1

Roots for Names of the Nonmetal Elements

Element	Root	Element	Root	Element	Root	Element	Root
C	carb	N	nitr	O	ox	F	fluor
		P	phosph	S	sulf	Cl	chlor
				Se	selen	Br	brom
						I	iod

OBJECTIVE 2

Table 6.2

Names of the Monatomic Anions

Anion	Name	Anion	Name	Anion	Name
N^{3-}	nitride	O^{2-}	oxide	H^-	hydride
P^{3-}	phosphide	S^{2-}	sulfide	F^-	fluoride
		Se^{2-}	selenide	Cl^-	chloride
				Br^-	bromide
				I^-	iodide

OBJECTIVE 2

The names of monatomic cations always start with the name of the metal, sometimes followed by a Roman numeral to indicate the charge of the ion. For example, Cu^+ is copper(I), and Cu^{2+} is copper(II). The Roman numeral in each name represents the charge on the ion and allows us to distinguish between more than one possible charge. Note that there is no space between the end of the name of the metal and the parentheses with the Roman numeral.

If the atoms of an element always have the same charge, the Roman numeral is unnecessary (and considered to be incorrect). For example, all cations formed from sodium atoms have a +1 charge, so Na^+ is named sodium ion, without the Roman numeral for the charge. The following elements have only one possible charge, so it would be incorrect to put a Roman numeral after their name.

- The alkali metals in group 1 are always +1 when they form cations.
- The alkaline earth metals in group 2 are always +2 when they form cations.
- Aluminum and the elements in group 3 are always +3 when they form cations.
- Zinc and cadmium always form +2 cations.

Although silver can form both +1 and +2 cations, the +2 is so rare that we usually name Ag^+ as *silver ion*, not *silver(I) ion*. Ag^{2+} is named silver(II) ion.

We will assume that all of the metallic elements other than those mentioned above can have more than one charge, so their cation names will include a Roman numeral. For example, Mn^{2+} is named manganese(II). We know to put the Roman numeral in the name because manganese is not on our list of metals with only one charge.

EXAMPLE 6.1 - Naming Monatomic Ions

Write names that correspond to the following formulas for monatomic ions: (a) Ba^{2+} , (b) S^{2-} , and (c) Cr^{3+} .

OBJECTIVE 2

Solution

- Because barium is in group 2, the only possible charge is +2. When there is only one possible charge, metallic ions are named with the name of the metal. Therefore, Ba^{2+} is **barium ion**.
- Monatomic anions are named with the root of the nonmetal and -ide, so S^{2-} is **sulfide ion**.
- Because chromium is not on our list of metals with only one possible charge, we need to indicate the charge with a Roman numeral. Therefore, Cr^{3+} is **chromium(III) ion**.

EXERCISE 6.1 - Naming Monatomic Ions

Write names that correspond to the following formulas for monatomic ions: (a) Mg^{2+} , (b) F^- , and (c) Sn^{2+} .

OBJECTIVE 2

EXAMPLE 6.2 - Formulas for Monatomic Ions

Write formulas that correspond to the following names for monatomic ions: (a) phosphide ion, (b) lithium ion, and (c) cobalt(II) ion.

OBJECTIVE 2

Solution

- We know this is a monatomic anion because it has the form, (*nonmetal root*) *ide*. Phosphorus atoms gain three electrons to get 18 electrons like the noble gas argon, Ar. Phosphide ion is P^{3-} .
- Lithium atoms lose one electron to get two electrons, like the noble gas helium. Lithium ion is Li^+ .
- The Roman numeral indicates that the cobalt ion has a +2 charge. Notice that we would not have been able to determine this from cobalt's position on the periodic table. Cobalt(II) is Co^{2+} .

There are two tutorials on the textbook's Web site that provide practice converting between names and formulas of cations and anions.

EXERCISE 6.2 - Formulas for Monatomic Ions

Write formulas that correspond to the following names for monatomic ions: (a) bromide ion, (b) aluminum ion, and (c) gold(I) ion.

OBJECTIVE 2

It is very useful to be able to convert between the names and formulas of the common polyatomic ions listed in Table 6.3. Check with your instructor to find out which of these you will be expected to know and whether there are others you should know as well.

OBJECTIVE 4

Table 6.3
Common Polyatomic Ions

Ion	Name	Ion	Name	Ion	Name
NH_4^+	ammonium	PO_4^{3-}	phosphate	SO_4^{2-}	sulfate
OH^-	hydroxide	NO_3^-	nitrate	$\text{C}_2\text{H}_3\text{O}_2^-$	acetate
CO_3^{2-}	carbonate				

OBJECTIVE 5

Some polyatomic anions are formed by the attachment of one or more hydrogen atoms. In fact, it is common for hydrogen atoms to be transferred from one ion or molecule to another ion or molecule. When this happens, the hydrogen atom is usually transferred without its electron, as H^+ . If an anion has a charge of -2 or -3 , it can gain one or two H^+ ions and still retain a negative charge. For example, carbonate, CO_3^{2-} , can gain an H^+ ion to form HCO_3^- , which is found in baking soda. The sulfide ion, S^{2-} , can gain one H^+ ion to form HS^- . Phosphate, PO_4^{3-} , can gain one H^+ ion and form HPO_4^{2-} , or it can gain two H^+ ions to form H_2PO_4^- . Both HPO_4^{2-} and H_2PO_4^- are found in flame retardants. These polyatomic ions are named with the word *hydrogen* in front of the name of the anion if there is one H^+ ion attached and *dihydrogen* in front of the name of the anion if two H^+ ions are attached.

HCO_3^- is hydrogen carbonate ion.

HS^- is hydrogen sulfide ion.

HPO_4^{2-} is hydrogen phosphate ion.

H_2PO_4^- is dihydrogen phosphate ion.

OBJECTIVE 6

Some polyatomic ions also have nonsystematic names that are often used. For example, HCO_3^- is often called bicarbonate instead of hydrogen carbonate. You should avoid using this less accepted name, but because many people still use it, you should know it.

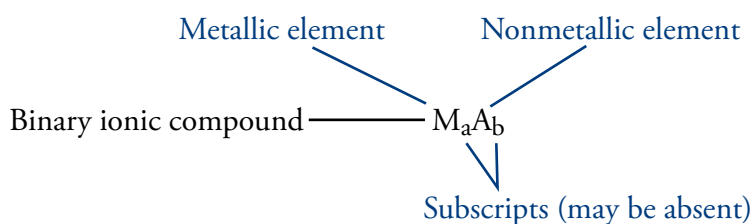
You can find a more comprehensive description of polyatomic ions, including a longer list of their names and formulas at the textbook's Web site.

Converting Formulas to Names for Ionic Compounds

There are many different types of chemical compounds, and each type has its own set of systematic guidelines for writing names and chemical formulas. Thus, to write the name that corresponds to a formula for a compound, you need to develop the ability to recognize the formula as representing a specific type of compound. Likewise, to write a formula from a name, you need to recognize the type of compound the name represents. You also need to learn the guidelines for converting between names and formulas for that type of compound. A chemical formula for an ionic compound will have one of the following forms.

OBJECTIVE 7

- Metal-nonmetal:*** Ionic compounds whose formula contains one symbol for a metal and one symbol for a nonmetal are called **binary ionic compounds**. Their general formula is M_aA_b , with M representing the symbol of a metallic element, A representing the symbol for a nonmetallic element, and lowercase a and b representing subscripts in the formula (unless one or more of the subscripts are assumed to be 1). For example, NaF (used to fluoridate municipal waters), $MgCl_2$ (used in floor sweeping compounds), and Al_2O_3 (in ceramic glazes) represent binary ionic compounds.



- Metal-polyatomic ion:*** Polyatomic ions can take the place of monatomic anions, so formulas that contain a symbol for a metallic element and the formula for a polyatomic ion represent ionic compounds. For example, $NaNO_3$ (in solid rocket propellants) and $Al_2(SO_4)_3$ (a foaming agent in fire foams) represent ionic compounds.
- Ammonium-nonmetal or ammonium-polyatomic ion:*** Ammonium ions, NH_4^+ , can take the place of metallic cations in an ionic compound, so chemical formulas that contain the formula for ammonium with either a symbol for a nonmetallic element or a formula for a polyatomic ion represent ionic compounds. For example, NH_4Cl (in dry cell batteries), $(NH_4)_2S$ (used to color brass), and $(NH_4)_2SO_4$ (in fertilizers) represent ionic compounds.



OBJECTIVE 7

The names of ionic compounds consist of the name for the cation followed by the name for the anion. Tables 6.4 and 6.5 summarize the ways cations and anions are named.

OBJECTIVE 7

Table 6.4
Summary of the Ways Cations Are Named

Type of cation	General name	Example
metal with one possible charge (groups 1, 2, 3–Al, Zn, and Cd)	name of metal	Mg ²⁺ is magnesium.
metal with more than one possible charge (the rest of the metallic elements)	name of metal (Roman numeral)	Cu ²⁺ is copper(II).
polyatomic cations (for us, only ammonium)	name of polyatomic cation	NH ₄ ⁺ is ammonium.

OBJECTIVE 7

Table 6.5
Summary of the Ways Anions Are Named

Type of anion	General name	Example
monatomic anions	(root of nonmetal)ide	O ²⁻ is oxide.
polyatomic anions	name of polyatomic anion	NO ₃ ⁻ is nitrate.

As an example of the thought-process for naming ionic compounds, let's write the name for MnO (used as a food additive and dietary supplement). Our first step is to identify the type of compound it represents. Because it is composed of a metallic element and a nonmetallic element, we recognize it as ionic. Thus we must write the name of the cation followed by the name of the anion. Manganese is not on our list of metallic elements with only one possible charge, so the cation's name is the name of the element followed by a Roman numeral that represents the charge. Therefore, our next step is to determine the charge on each manganese cation in MnO.

When the cation in an ionic formula is created from a metallic element whose atoms can have more than one charge, you can discover the cation's charge by identifying the charge on the anion and then figuring out what charge the cation must have to yield a formula that is uncharged overall. To discover the charge on the manganese ions in MnO, you first determine the charge on the anions. A glance at the periodic table shows oxygen to be in group 16, or 6A, whose nonmetallic members always form -2 ions. With x representing the charge on the manganese ion, the charge on the manganese cation can be figured out as follows:

$$\begin{aligned} \text{total cation charge} + \text{total anion charge} &= 0 \\ x + (-2) &= 0 \\ x &= +2 \end{aligned}$$

OBJECTIVE 7

Each manganese cation must therefore be $+2$ to balance the -2 of the oxide to yield an uncharged ionic formula. The systematic name for Mn²⁺ is *manganese(II)*. Monatomic anions are named with the root of the nonmetal followed by *-ide*, so O²⁻ is *oxide*. MnO is named manganese(II) oxide. Example 6.3 provides other examples.

EXAMPLE 6.3 - Formulas for Monatomic Ions

Write the names that correspond to the following formulas: (a) MgO (used to make aircraft windshields), (b) CoCl₂ (used to manufacture vitamin B-12), (c) NH₄NO₃ (used to make explosives), and (d) Fe₂O₃ (in paint pigments).

Solution

- a. The compound MgO includes the cation Mg²⁺ and the anion O²⁻. Magnesium cations are always +2, so the name of the cation is the same as the name of the metallic element. The anion O²⁻ is monatomic, so it is named by combining the root of the name of the nonmetal with -ide. Therefore, MgO is **magnesium oxide**.
- b. Cobalt is not on our list of metallic elements that form ions with only one charge, so we assume it can form ions with more than one possible charge. Therefore, we need to show the charge on the cobalt ion with a Roman numeral in parentheses after the name cobalt. The cobalt ion must be +2 to balance the -2 from the two -1 chloride ions.

$$\text{Total cation charge} + \text{total anion charge} = 0$$

$$x + 2(-1) = 0$$

$$x = +2$$

The anion Cl⁻ is monatomic, so its name includes the root of the name of the nonmetal and -ide. Therefore, CoCl₂ is **cobalt(II) chloride**.

- c. The compound NH₄NO₃ includes the cation NH₄⁺ and the anion NO₃⁻. Both of these ions are polyatomic ions with names you should memorize. The name of NH₄NO₃ is **ammonium nitrate**.
- d. Iron is not on our list of metallic elements that form ions with only one charge, so we need to show the charge on the iron ion with a Roman numeral. Because oxygen atoms have two fewer electrons than the nearest noble gas, neon, they form -2 ions. In the following equation, x represents the charge on each iron ion. Because there are two iron ions, $2x$ represents the total cation charge. Likewise, because there are three oxygen ions, the total anion charge is three times the charge on each oxygen ion.

$$\text{total cation charge} + \text{total anion charge} = 0$$

$$2x + 3(-2) = 0$$

$$x = +3$$

The iron ions must be +3 in order for them to balance the -6 from three -2 oxide ions, so the cation name is iron(III). Because O²⁻ is a monatomic anion, its name includes the root of the name of the nonmetal and -ide. Therefore, Fe₂O₃ is **iron(III) oxide**.

OBJECTIVE 7



CoCl₂ is used to make vitamin B-12.

EXERCISE 6.3 - Naming Ionic Compounds

Write the names that correspond to the following formulas: (a) LiCl (used in soft drinks to help reduce the escape of bubbles), (b) Cr₂(SO₄)₃ (used in chrome plating), and (c) NH₄HCO₃ (used as a leavening agent for cookies, crackers, and cream puffs).

OBJECTIVE 7

Converting Names of Ionic Compounds to Formulas

OBJECTIVE 7

Before you can write a chemical formula from the name of a compound, you need to recognize what type of compound the name represents. For binary ionic compounds, the first part of the name is the name of a metallic cation. This may include a Roman numeral in parentheses. The anion name starts with the root of the name of a nonmetal and ends with *-ide*.

(name of metal)(maybe Roman numeral) (root of nonmetal)ide

For example, aluminum fluoride (used in the production of aluminum) and tin(II) chloride (used in galvanizing tin) are binary ionic compounds.

You can identify other names as representing ionic compounds by recognizing that they contain the names of common polyatomic ions. For example, ammonium chloride and iron(III) hydroxide are both ionic compounds. Many of the polyatomic ions that you will be expected to recognize end in *-ate*, so this ending tells you that the name represents an ionic compound. Copper(II) sulfate is an ionic compound.

Follow these steps to write formulas for ionic compounds.

STEP 1 Write the formula, including the charge, for the cation. (See Figure 5.10 to review the charges on monatomic cations.)

STEP 2 Write the formula, including the charge, for the anion. (See Figure 5.10 to review the charges on monatomic anions. See Table 6.3 to review polyatomic ion formulas.)

STEP 3 Write subscripts for each formula so as to yield an uncharged compound. Table 6.6 shows examples.

- Use the lowest whole number ratio for the subscripts.
- If the subscript for a polyatomic ion is higher than one, place the formula for the polyatomic ion in parentheses and put the subscript outside the parentheses.

OBJECTIVE 7

Table 6.6

Possible Cation-Anion Ratios (X represents the cation, and Y represents the anion.)

Ionic charges	General formula	Example ions	Example formula
X^+ and Y^-	XY	Na^+ and Cl^-	NaCl
X^+ and Y^{2-}	X_2Y	NH_4^+ and SO_4^{2-}	$(NH_4)_2SO_4$
X^+ and Y^{3-}	X_3Y	Li^+ and PO_4^{3-}	Li_3PO_4
X^{2+} and Y^-	XY_2	Mg^{2+} and NO_3^-	$Mg(NO_3)_2$
X^{2+} and Y^{2-}	XY	Ca^{2+} and CO_3^{2-}	$CaCO_3$
X^{2+} and Y^{3-}	X_3Y_2	Ba^{2+} and N^{3-}	Ba_3N_2
X^{3+} and Y^-	XY_3	Al^{3+} and F^-	AlF_3
X^{3+} and Y^{2-}	X_2Y_3	Sc^{3+} and S^{2-}	Sc_2S_3
X^{3+} and Y^{3-}	XY	Fe^{3+} and PO_4^{3-}	$FePO_4$

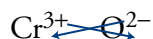


EXAMPLE 6.4 - Formulas for Ionic Compounds

Write the chemical formulas that correspond to the following names: (a) aluminum chloride (used in cosmetics), (b) chromium(III) oxide (a pigment for coloring pottery glazes), (c) calcium nitrate (provides a red-orange color in fireworks), and (d) ammonium sulfide (used to make synthetic flavors).

Solution

- Aluminum chloride has the form (*name of metal*) (*root of nonmetal*)*ide*, so we recognize it as a binary ionic compound. Because aluminum atoms have three more electrons than the nearest noble gas, neon, they lose three electrons and form $+3$ ions. Because chlorine atoms have one fewer electron than the nearest noble gas, argon, they gain one electron to form -1 ions. The formulas for the individual ions are Al^{3+} and Cl^- . It would take three chlorides to neutralize the $+3$ aluminum ion, so the formula for the compound is AlCl_3 .
- Chromium(III) oxide has the form (*name of metal*)(*Roman numeral*) (*root of nonmetal*)*ide*, so it represents a binary ionic compound. The (*III*) tells you that the chromium ions have a $+3$ charge. Because oxygen atoms have two fewer electrons than the nearest noble gas, neon, they gain two electrons to form -2 ions. The formulas for the ions are Cr^{3+} and O^{2-} . When the ionic charges are $+3$ and -2 (or $+2$ and -3), a simple procedure will help you to determine the subscripts in the formula. Disregarding the signs of the charges, use the superscript on the anion as the subscript on the cation, and use the superscript on the cation as the subscript on the anion.



Chromium(III) oxide is Cr_2O_3 .

- Calcium nitrate has the form (*name of metal*) (*name of a polyatomic ion*), so it represents an ionic compound. (The *-ate* at the end of nitrate tells us that it is a polyatomic ion.) Calcium is in group 2 on the periodic table. Because all metals in group 2 have two more electrons than the nearest noble gas, they all lose two electrons and form $+2$ ions. Nitrate is NO_3^- , so two nitrate ions are needed to neutralize the charge on the Ca^{2+} . Calcium nitrate is $\text{Ca}(\text{NO}_3)_2$. Note that in order to show that there are two nitrate ions, the formula for nitrate is placed in parentheses.
- Ammonium sulfide has the form *ammonium* (*root of a nonmetal*)*ide*, so it represents an ionic compound. You should memorize the formula for ammonium, NH_4^+ . Sulfur has two fewer electrons than the noble gas, argon, so it gains two electrons and forms a -2 anion. Two ammonium ions would be necessary to neutralize the -2 sulfide. Ammonium sulfide is $(\text{NH}_4)_2\text{S}$.

OBJECTIVE 7



Cr_2O_3 is a pigment used for coloring pottery glazes.

There is a tutorial on the textbook's Web site that provides practice converting between names and formulas of ionic compounds.

EXERCISE 6.4 - Formulas Ionic Compounds

Write the formulas that correspond to the following names: (a) aluminum oxide (used to waterproof fabrics), (b) cobalt(III) fluoride (used to add fluorine atoms to compounds), (c) iron(II) sulfate (in enriched flour), (d) ammonium hydrogen phosphate (coats vegetation to retard forest fires), and (e) potassium bicarbonate (in fire extinguishers).

OBJECTIVE 7

6.2 Binary Covalent Nomenclature



The purpose of this section is to describe the guidelines for constructing the names for **binary covalent compounds**, which are pure substances that consist of two nonmetallic elements. The water, H_2O , you boil to cook your eggs and the methane, CH_4 , in natural gas that can be burned to heat the water are examples of binary covalent compounds.

OBJECTIVE 8

Memorized Names

Some binary covalent compounds, such as water, H_2O , and ammonia, NH_3 , are known by common names that chemists have used for years. There is no systematic set of rules underlying these names, so each must simply be memorized. Organic compounds, such as methane, CH_4 , ethane, C_2H_6 , and propane, C_3H_8 , are named by a systematic procedure that you might learn later in your chemical education, but for now, it will be useful to memorize some of their names and formulas also (Table 6.7).

OBJECTIVE 8

Table 6.7

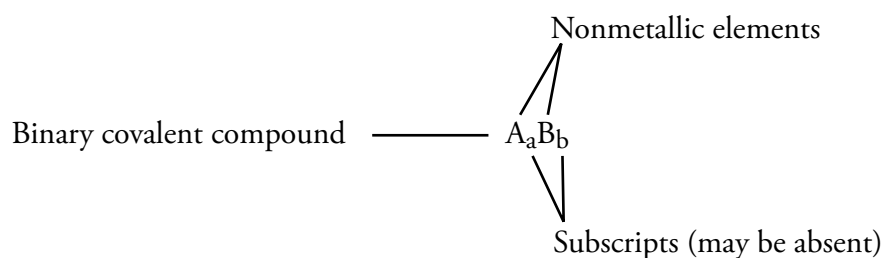
Names and Formulas of some Binary Covalent Compounds

Name	Formula	Name	Formula
water	H_2O	ammonia	NH_3
methane	CH_4	ethane	C_2H_6
propane	C_3H_8		

Systematic Names

As we noted earlier, chemists have established different sets of rules for writing the names and formulas of different types of chemical compounds, so the first step in writing a name from a chemical formula is to decide what type of compound the formula represents. You can recognize binary covalent compounds from their formulas, which contain symbols for only two nonmetallic elements. The general pattern of such formulas is A_aB_b , where “A” and “B” represent symbols for nonmetals, and “a” and “b” represent subscripts (remember that if one of the subscripts is absent, it is understood to be 1). For example, because nitrogen and oxygen are nonmetallic elements, the formula N_2O_3 represents a binary covalent compound.

OBJECTIVE 9



Follow these steps to write the names for binary covalent compounds.

- If the subscript for the first element is greater than one, indicate the identity of the subscript using prefixes from Table 6.8. We do not write *mono-* at the beginning of a compound's name (see Example 6.5).

Example: We start the name for N_2O_3 with *di-*.

Table 6.8

Prefixes Used in the Names of Binary Covalent Compounds

OBJECTIVE 10

Number of atoms	Prefix	Number of atoms	Prefix
1	mon(o)	6	hex(a)
2	di	7	hept(a)
3	tri	8	oct(a)
4	tetr(a)	9	non(a)
5	pent(a)	10	dec(a)

- Attach the selected prefix to the name of the first element in the formula. If no prefix is to be used, begin with the name of the first element.
Example: We indicate the N_2 portion of N_2O_3 with *dinitrogen*.
- Select a prefix to identify the subscript for the second element (even if its subscript is understood to be one). Leave the *a* off the end of the prefixes that end in *a* and the *o* off of *mono-* if they are placed in front of an element whose name begins with a vowel (oxygen or iodine).
Example: The name of N_2O_3 grows to *dinitrogen tri-*.
- Write the root of the name of the second element in the formula as shown in Table 6.1.
Example: The name of N_2O_3 becomes *dinitrogen triox-*.
- Add *-ide* to the end of the name.
Example: The name of N_2O_3 is *dinitrogen trioxide*.

EXAMPLE 6.5 - Naming Binary Covalent Compounds

Write the names that correspond to the formulas (a) N_2O_5 , (b) NO_2 , and (c) NO .

Solution

These formulas are in the form of A_aB_b , where A and B represent symbols for nonmetallic elements, so they are binary covalent compounds.

- The first subscript in N_2O_5 is 2, so the first prefix is *di*. The first symbol, N, represents nitrogen, so the name for N_2O_5 begins with *dinitrogen*. The second subscript is 5, and the second symbol, O, represents oxygen. Therefore, the prefix *pent* combines with the root of oxygen, *ox*, and the usual ending, *ide*, to give *pentoxide* for the second part of the name. N_2O_5 is **dinitrogen pentoxide**. Note that the *a* is left off *penta*, because the root *ox* begins with a vowel.
- NO_2 is **nitrogen dioxide**. We leave *mono* off the first part of the name.
- NO is **nitrogen monoxide**. We leave *mono* off the first part of the name, but we start the second part of the name with *mon*. The *o* in *mono* is left off before the root *ox*.

OBJECTIVE 12

OBJECTIVE 11

Hydrogen atoms always form one covalent bond, and halogen atoms (group 17 or 7A) usually form one bond. Thus hydrogen reacts with halogens to form compounds with the general formula of HX, with the X representing the halogen. Because this is common knowledge among scientists and science students, these compounds are often named without prefixes. For example, HF can be named hydrogen fluoride or hydrogen monofluoride. Likewise, HCl can be named hydrogen chloride or hydrogen monochloride, HBr can be named hydrogen bromide or hydrogen monobromide, and HI can be named hydrogen iodide or hydrogen moniodide. For similar reasons, H₂S can be named hydrogen sulfide or dihydrogen monosulfide.

EXERCISE 6.5 - Naming of Binary Covalent Compounds

OBJECTIVE 12

Write names that correspond to the following formulas: (a) P₂O₅, (b) PCl₃, (c) CO, (d) H₂S, and (e) NH₃.

Converting Names of Binary Covalent Compounds to Formulas

Now let's go the other way and convert from systematic names to chemical formulas.

OBJECTIVE 9

The first step in writing formulas when given the systematic name of a binary covalent compound is to recognize the name as representing a binary covalent compound. It will have one of the following general forms.

prefix(name of nonmetal) prefix(root of name of nonmetal)ide

(for example, dinitrogen pentoxide)

or (name of nonmetal) prefix(root of name of nonmetal)ide

(for example, carbon dioxide)

or (name of nonmetal) (root of nonmetal)ide

(for example, hydrogen fluoride)

OBJECTIVE 12

Follow these steps for writing formulas for binary covalent compounds when you are given a systematic name. Note that they are the reverse of the steps for writing names from chemical formulas.

- Write the symbols for the elements in the order mentioned in the name.
- Write subscripts indicated by the prefixes. If the first part of the name has no prefix, assume it is mono-.

Remember that HF, HCl, HBr, HI, and H₂S are often named without prefixes. You will also be expected to write formulas for the compounds whose nonsystematic names are listed in Table 6.7.

EXAMPLE 6.6 - Writing Formulas for Binary Covalent Compounds

Write the formulas that correspond to the following names: (a) dinitrogen tetroxide, (b) phosphorus tribromide, (c) hydrogen iodide, and (d) methane.

OBJECTIVE 12

Solution

- a. Because the name dinitrogen tetroxide has the following form, it must be binary covalent.

prefix(name of nonmetal) prefix(root of name of nonmetal)ide

The di- tells us there are two nitrogen atoms, and the tetr- tells us there are four oxygen atoms. Dinitrogen tetroxide is N_2O_4 .

- b. Because the name phosphorus tribromide has the following form, it must be binary covalent.

(name of nonmetal) prefix(root of name of nonmetal)ide

Because there is no prefix attached to phosphorus, we assume there is one phosphorus atom. Phosphorus tribromide is PBr_3 .

- c. Because the name hydrogen iodide has the following form, it must be binary covalent.

(name of nonmetal) (root of name of nonmetal)ide

This is one of the binary covalent compounds that do not require prefixes. Iodine usually forms one bond, and hydrogen always forms one bond, so hydrogen iodide is HI .

- d. Methane is on our list of binary covalent compounds with names you should memorize. Methane is CH_4 .

There is a tutorial on the textbook's Web site that provides practice converting between names and formulas of binary covalent compounds.

EXERCISE 6.6 - Writing Formulas for Binary Covalent Compounds

Write formulas that correspond to the following names: (a) disulfur decafluoride, (b) nitrogen trifluoride, (c) propane, and (d) hydrogen chloride.

OBJECTIVE 12

6.3 Acids

OBJECTIVE 13



Acids have many uses, including making car batteries, softdrinks, artificial sweeteners, and napkins.

You may have already noticed, in your first few weeks of studying chemistry, that the more you learn about matter, the more ways you have of grouping and classifying the different substances. The most common and familiar way of classifying substances is by their noteworthy properties. For example, people long ago decided that any substance that has a sour taste is an acid. Lemons are sour because they contain citric acid, and old wine that has been exposed to the air tastes sour due to acetic acid. As chemists learned more about these substances, however, they developed more specific definitions that allowed classification without relying on taste. A good thing, too, because many acids and bases should not be tasted—or even touched. They speed the breakdown of some of the substances that form the structure of our bodies or that help regulate the body's chemical changes.

Two different definitions of acid are going to be of use to us. For example, chemists conduct many laboratory experiments using a reagent known as “nitric acid,” a substance that has been classified as an acid according to the Arrhenius definition of acid (named after the Swedish Nobel prize-winning chemist, Svante August Arrhenius). Arrhenius recognized that when ionic compounds dissolve, they form ions in solution. (For example, when sodium chloride dissolves, it forms sodium ions and chloride ions.) He postulated that acids dissolve in a similar way to form H^+ ions and some kind of anion. For example, he predicted that when HCl is added to water, H^+ ions and Cl^- ions form. We now know that H^+ ions do not persist in water; they combine with water molecules to form hydronium ions, H_3O^+ . Therefore, according to the modern form of the Arrhenius theory, an **acid** is a substance that produces **hydronium ions**, H_3O^+ , when it is added to water. On the basis of this definition, an **acidic solution** is a solution with a significant concentration of H_3O^+ . For reasons that are described in Chapter 8, chemists often find this definition too limiting, so another, broader definition of acids, called the Brønsted-Lowry definition, which is described in Section 8.4, is commonly used instead.

OBJECTIVE 14

To get an understanding of how hydronium ions are formed when Arrhenius acids are added to water, let's consider the dissolving of gaseous hydrogen chloride, $HCl(g)$, in water. The solution that forms is called hydrochloric acid. When HCl molecules dissolve in water, a chemical change takes place in which water molecules pull hydrogen atoms away from HCl molecules. In each case, the hydrogen atom is transferred without its electron, that is, as an H^+ ion, and because most uncharged hydrogen atoms contain only one proton and one electron, most hydrogen atoms without their electrons are just protons. For this reason, the hydrogen ion, H^+ , is often called a proton. We say that the HCl donates a proton, H^+ , to water, forming hydronium ion, H_3O^+ , and chloride ion, Cl^- (Figure 6.1).

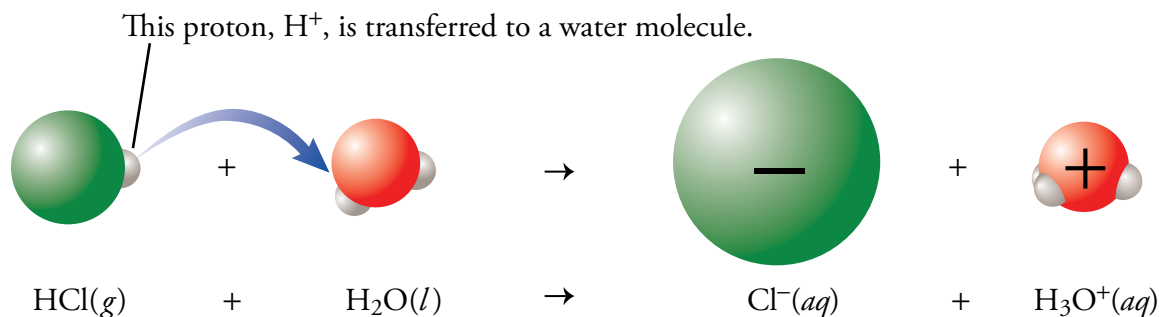


Figure 6.1
HCl Reaction with Water

Because HCl produces hydronium ions when added to water, it is an acid according to the Arrhenius definition of acids. Once the chloride ion and the hydronium ion are formed, the negatively charged oxygen atoms of the water molecules surround the hydronium ion, and the positively charged hydrogen atoms of the water molecules surround the chloride ion. Figure 6.2 shows how you can picture this solution.

OBJECTIVE 14

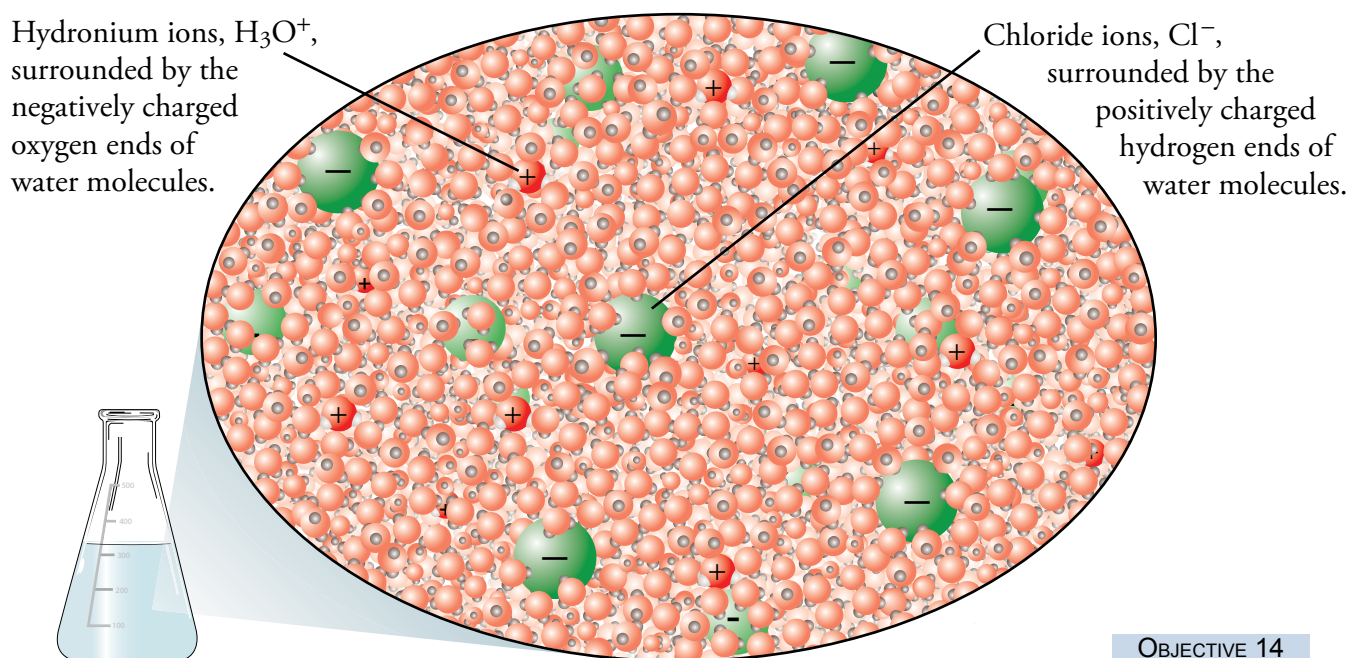


Figure 6.2
Hydrochloric Acid in Water

Hydrochloric acid solutions are used in the chemical industry to remove impurities from metal surfaces (this is called pickling), to process food, to increase the permeability of limestone (an aid in oil drilling), and to make many important chemicals.

Types of Arrhenius Acids

OBJECTIVE 15

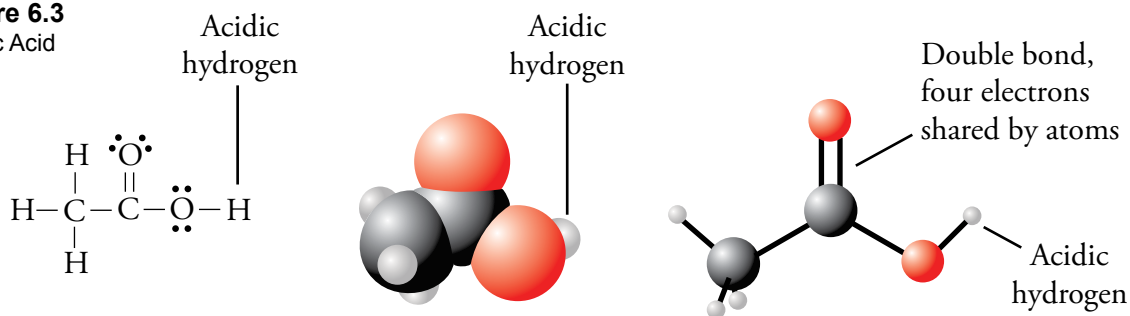
In terms of chemical structure, Arrhenius acids can be divided into several different subcategories. We will look at three of them here: binary acids, oxyacids, and organic acids. The **binary acids** are $\text{HF}(aq)$, $\text{HCl}(aq)$, $\text{HBr}(aq)$, and $\text{HI}(aq)$; all have the general formula of $\text{HX}(aq)$, where X is one of the first four halogens. The formulas for the binary acids will be followed by (aq) in this text to show that they are dissolved in water. The most common binary acid is hydrochloric acid, $\text{HCl}(aq)$.

Oxyacids (often called oxoacids) are molecular substances that have the general formula $\text{H}_a\text{X}_b\text{O}_c$. In other words, they contain hydrogen, oxygen, and one other element represented by X; the a , b , and c represent subscripts. The most common oxyacids in the chemical laboratory are nitric acid, HNO_3 , and sulfuric acid, H_2SO_4 .

OBJECTIVE 16

Acetic acid, the acid responsible for the properties of vinegar, contains hydrogen, oxygen, and carbon and therefore fits the criteria for classification as an oxyacid, but it is more commonly described as an organic (or carbon-based) acid. It can also be called a carboxylic acid. (This type of acid is described in more detail in Section 15.1.) The formula for acetic acid can be written as either $\text{HC}_2\text{H}_3\text{O}_2$, $\text{CH}_3\text{CO}_2\text{H}$, or CH_3COOH . The reason for keeping one H in these formulas separate from the others is that the hydrogen atoms in acetic acid are not all equal. Only one of them can be transferred to a water molecule. That hydrogen atom is known as the acidic hydrogen. We will use the formula $\text{HC}_2\text{H}_3\text{O}_2$ because it is more consistent with the formulas for other acids presented in this chapter. The Lewis structure, space-filling model, and ball-and-stick model for acetic acid (Figure 6.3) show why $\text{CH}_3\text{CO}_2\text{H}$, and CH_3COOH are also common. The acidic hydrogen is the one connected to an oxygen atom.

Figure 6.3
Acetic Acid



Pure acetic acid freezes at $17\text{ }^\circ\text{C}$ ($63\text{ }^\circ\text{F}$). Therefore, it is a liquid at normal room temperature, but if you put it outside on a cold day, it will freeze. The solid has layered crystals that look like tiny glaciers, so pure acetic acid is called glacial acetic acid. The chemical industry uses acetic acid to make several substances necessary for producing latex paints, safety glass layers, photographic film, cigarette filters, magnetic tapes, and clothing. Acetic acid is also used to make esters, which are substances that have very pleasant odors and are added to candy and other foods.

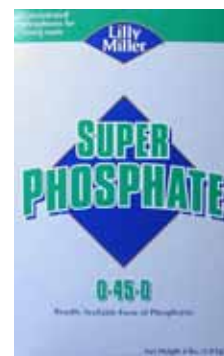
Acids can have more than one acidic hydrogen. If each molecule of an acid can donate one hydrogen ion, the acid is called a **monoprotic acid**. If each molecule can donate two or more hydrogen ions, the acid is a **polyprotic acid**. A **diprotic acid**, such as sulfuric acid, H_2SO_4 , has two acidic hydrogen atoms. Some acids, such as phosphoric acid, H_3PO_4 , are **triprotic acids**. Most of the phosphoric acid produced

by the chemical industry is used to make fertilizers and detergents, but it is also used to make pharmaceuticals, to refine sugar, and in water treatment. The tartness of some foods and beverages comes from acidifying them by adding phosphoric acid. The space-filling model in Figure 6.4 shows the three acidic hydrogen atoms of phosphoric acid.

Strong and Weak Acids

Although hydrochloric acid and acetic acid are both acids according to the Arrhenius definition, the solutions created by dissolving the same numbers of HCl and HC₂H₃O₂ molecules in water have very different acid properties. You wouldn't hesitate to put a solution of the weak acid HC₂H₃O₂ (vinegar) on your salad, but putting a solution of the strong acid HCl on your salad would have a very different effect on the lettuce. With hydrochloric acid, you are more likely to get a brown, fuming mess rather than a crisp, green salad. **Strong acids** form nearly one H₃O⁺ ion in solution for each acid molecule dissolved in water, whereas **weak acids** yield significantly less than one H₃O⁺ ion in solution for each acid molecule dissolved in water.

When an acetic acid molecule, HC₂H₃O₂, collides with an H₂O molecule, an H⁺ can be transferred to the water to form a hydronium ion, H₃O⁺, and an acetate ion, C₂H₃O₂⁻. The acetate ion, however, is less stable in solution than the chloride ion formed when the strong acid HCl dissolves in water. Because of this instability, the C₂H₃O₂⁻ reacts with the hydronium ion, pulling the H⁺ ion back to reform HC₂H₃O₂ and H₂O. A reaction in which the reactants are constantly forming products and, at the same time, the products are re-forming the reactants is called a **reversible reaction**. The chemical equations for reactions that are significantly reversible are written with double arrows as illustrated in Figure 6.5.



Acidic hydrogen atoms

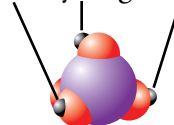
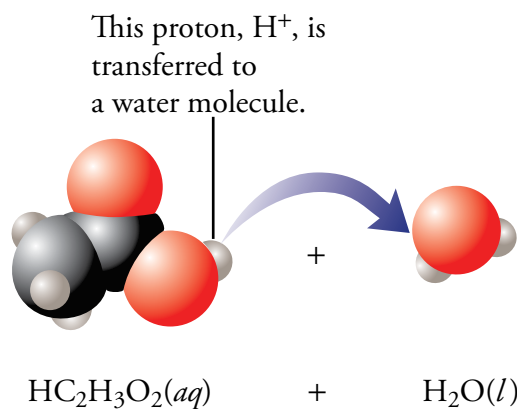


Figure 6.4
The phosphate in this fertilizer was made from phosphoric acid.

OBJECTIVE 17

OBJECTIVE 17



Indicates a reversible reaction

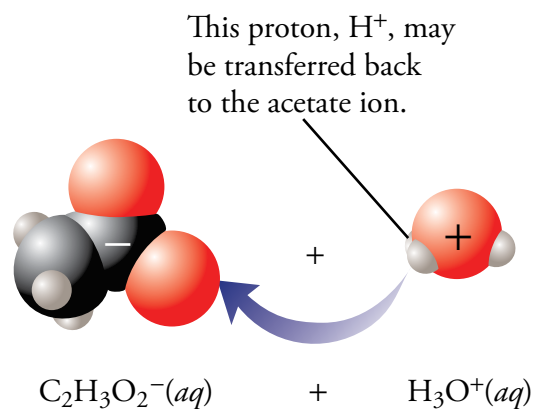


Figure 6.5
Reversible Reaction of Acetic Acid and Water

If you were small enough to be riding on one of the carbon atoms in HC₂H₃O₂ or C₂H₃O₂⁻, you would find that your atom was usually in the HC₂H₃O₂ form but often in the C₂H₃O₂⁻ form and continually changing back and forth. The forward and reverse reactions would be taking place simultaneously all around you. When acetic acid is added to water, the relative amounts of the different products and reactants

OBJECTIVE 17

soon reach levels at which the opposing reactions proceed at equal rates. (We will see why in Chapter 14.) This means that the forward reaction is producing $\text{C}_2\text{H}_3\text{O}_2^-$ as quickly as the reverse reaction is producing $\text{HC}_2\text{H}_3\text{O}_2(aq)$. At this point, there is no more net change in the amounts of $\text{HC}_2\text{H}_3\text{O}_2$, H_2O , $\text{C}_2\text{H}_3\text{O}_2^-$, or H_3O^+ in the solution. For example, for each 1000 molecules of acetic acid added to water, the solution will eventually contain about 996 acetic acid molecules ($\text{HC}_2\text{H}_3\text{O}_2$), four hydronium ions (H_3O^+), and four acetate ions ($\text{C}_2\text{H}_3\text{O}_2^-$). Acetic acid is therefore a **weak acid**, a substance that is incompletely ionized in water because of the reversibility of its reaction with water that forms hydronium ion, H_3O^+ . Figure 6.6 shows a simple model that will help you to picture this solution.

In a typical acetic acid solution, there are about 250 times as many uncharged acetic acid molecules, $\text{HC}_2\text{H}_3\text{O}_2$, as acetate ions, $\text{C}_2\text{H}_3\text{O}_2^-$.

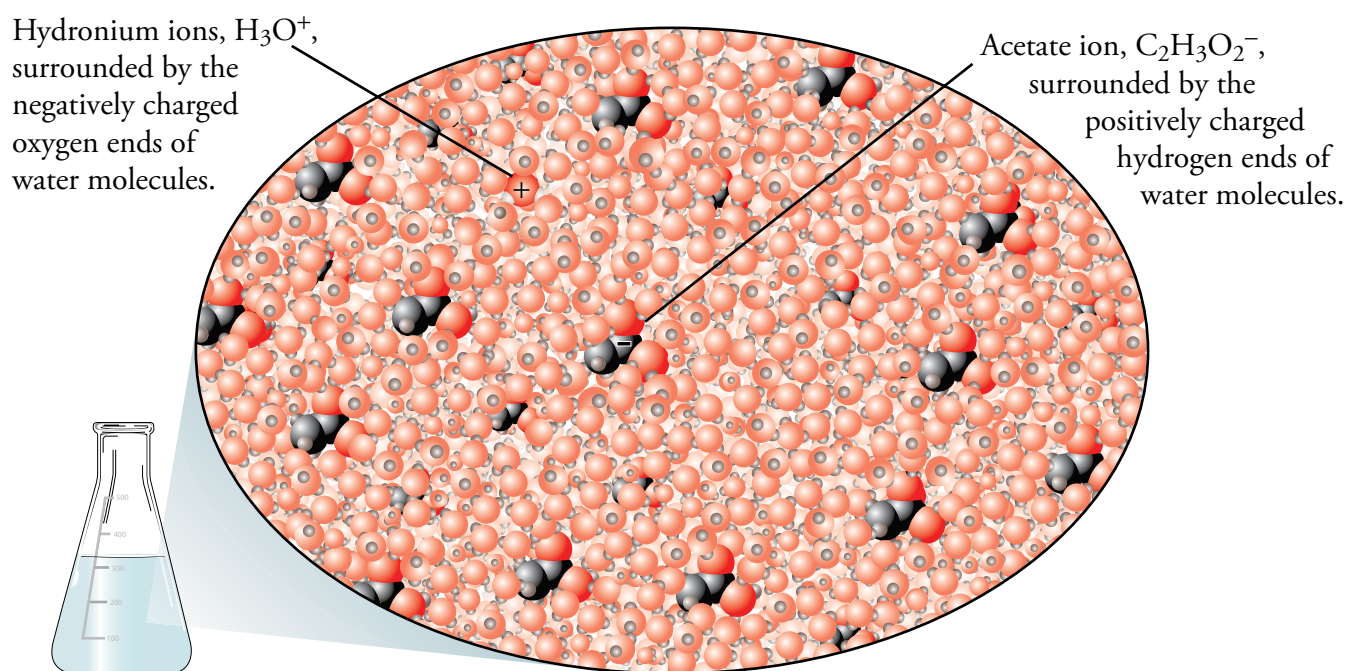
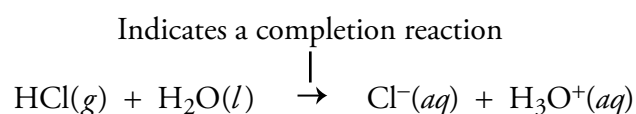


Figure 6.6
Acetic Acid in Water

OBJECTIVE 17

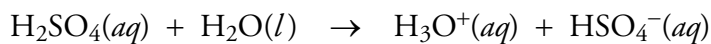
OBJECTIVE 18

The products formed from the reaction of a strong acid and water do not recombine at a significant rate to re-form the uncharged acid molecules and water. For example, when HCl molecules react with water, the H_3O^+ and Cl^- ions that form do not react to a significant degree to reform HCl and H_2O . (Look again at Figure 6.2 to see the behavior of a strong acid in solution.) Reactions like this that are not significantly reversible are often called **completion reactions**. The chemical equations for completion reactions are written with single arrows to indicate that the reaction proceeds to form almost 100% products.

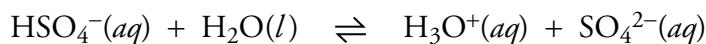


OBJECTIVE 20

Sulfuric acid, H_2SO_4 , is a strong diprotic acid. When added to water, each H_2SO_4 molecule loses its first hydrogen ion completely. This is the reason that H_2SO_4 is classified as a strong acid. Note the single arrow to indicate a completion reaction.



The hydrogen sulfate ion, HSO_4^- , which is a product of this reaction, is a weak acid. It reacts with water in a reversible reaction to form a hydronium ion and a sulfate ion. Note the double arrow to indicate a reversible reaction.



For each 100 sulfuric acid molecules added to water, the solution will eventually contain about 101 hydronium ions (H_3O^+), 99 hydrogen sulfate ions (HSO_4^-), and 1 sulfate ion (SO_4^{2-}).

Sulfuric acid, H_2SO_4 , is produced by the United States chemical industry in greater mass than any other chemical. Over 40 billion kilograms of H_2SO_4 are produced each year, to make phosphate fertilizers, plastics, and many other substances. Sulfuric acid is also used in ore processing, petroleum refining, pulp and paper-making, and for a variety of other purposes. Most cars are started by lead-acid storage batteries, which contain about 33.5% H_2SO_4 .

OBJECTIVE 22

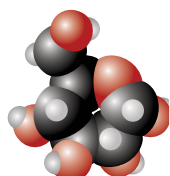
To do the Chapter Problems at the end of this chapter, you will need to identify important acids as being either strong or weak. The strong acids that you will be expected to recognize are hydrochloric acid, $\text{HCl}(aq)$, nitric acid, HNO_3 , and sulfuric acid, H_2SO_4 . An acid is considered weak if it is not on the list of strong acids. Table 6.9 summarizes this information.

OBJECTIVE 22

Table 6.9

Arrhenius Acids

	Strong	Weak
Binary Acids	hydrochloric acid, $\text{HCl}(aq)$	hydrofluoric acid, $\text{HF}(aq)$
Oxyacids	nitric acid, HNO_3 , sulfuric acid, H_2SO_4	other acids with the general formula $\text{H}_a\text{X}_b\text{O}_c$
Organic acids	None	acetic acid, $\text{HC}_2\text{H}_3\text{O}_2$, and others you will see in Section 15.1



Web
Molecules

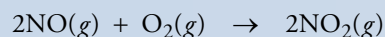
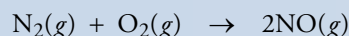
There is an animation that illustrates the differences between strong and weak acids at the textbook's Web site.

Special Topic 6.1 tells how acids are formed in the earth's atmosphere and how these acids can be damaging to our atmosphere.

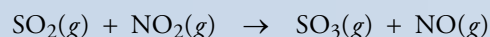
SPECIAL TOPIC 6.1 Acid Rain

Normal rainwater is very slightly acidic due to several reactions between substances dissolved in the water and the water itself. For example, carbon dioxide, nitrogen dioxide, and sulfur trioxide—all of which are natural components of air—react with water to form carbonic acid, nitric acid, and sulfuric acid.

Nitrogen dioxide is produced in nature in many ways, including a reaction between the oxygen and nitrogen in the air during electrical storms.



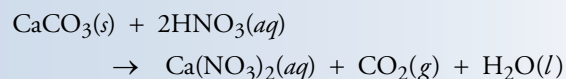
Sulfur dioxide also has natural sources, including the burning of sulfur-containing compounds in volcanic eruptions and forest fires. Sulfur dioxide is converted into sulfur trioxide, SO_3 , by reaction with the nitrogen dioxide in the air, among other mechanisms.



We humans have added considerably to the levels of $\text{NO}_2(g)$ and $\text{SO}_2(g)$ in our air, causing a steady increase in the acidity of rain. Coal, for example, contains a significant amount of sulfur; when coal is burned, the sulfur is

converted into sulfur dioxide, $\text{SO}_2(g)$. The sulfur dioxide is converted into sulfur trioxide, $\text{SO}_3(g)$, in the air, and that compound dissolves in rainwater and becomes sulfuric acid, $\text{H}_2\text{SO}_4(aq)$. As individuals, we also contribute to acid rain every time we drive a car around the block. When air, which contains nitrogen and oxygen, is heated in the cylinders of the car, the two gases combine to yield nitrogen monoxide, $\text{NO}(g)$, which is then converted into nitrogen dioxide, $\text{NO}_2(g)$, in the air. The NO_2 combines with water in rain to form nitric acid, $\text{HNO}_3(aq)$. There are many more H_3O^+ ions in the rain falling in the Northeastern United States than would be expected without human contributions.

The increased acidity of the rain leads to many problems. For example, the acids in acid rain react with the calcium carbonate in marble statues and buildings, causing them to dissolve. (Marble is compressed limestone, which is composed of calcium carbonate, $\text{CaCO}_3(s)$.)



A similar reaction allows a plumber to remove the calcium carbonate scale in your hot water pipes. If the pipes are washed in an acidic solution, the calcium carbonate dissolves.

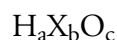
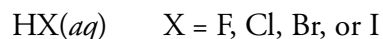


The statues on the left were transported by William Randolph Hearst to his home in San Simeon, California. Because it so rarely rains there, and because San Simeon is far from any major sources of pollution, these statues are in much better condition than the similar statues found elsewhere, such as the one on the right, that have been damaged by acid rain.



6.4 Acid Nomenclature

Like for other compounds, it is useful to be able to convert between names and formulas for acids. Remember that the names of Arrhenius acids usually end in acid (hydrochloric acid, sulfuric acid, nitric acid) and that their formulas fit one of two general patterns:



For example, $\text{HCl}(aq)$ (hydrochloric acid), H_2SO_4 (sulfuric acid), and HNO_3 (nitric acid) represent acids.

Names and Formulas of Binary Acids

OBJECTIVE 23

Binary acids are named by writing *hydro* followed by the root of the name of the halogen, then *-ic*, and finally *acid*:

hydro(root)ic acid

The only exception to remember is that the “o” in hydro is left off for $\text{HI}(aq)$, so its name is hydriodic acid (an acid used to make pharmaceuticals).

Most chemists refer to pure HCl gas as hydrogen chloride, but when HCl gas is dissolved in water, $\text{HCl}(aq)$, the solution is called hydrochloric acid. We will follow the same rule in this text, calling HCl or $\text{HCl}(g)$ hydrogen chloride and calling $\text{HCl}(aq)$ hydrochloric acid. The same pattern holds for the other binary acids as well.

You will be expected to be able to write formulas and names for the binary acids found on Table 6.10. Remember that it is a good habit to write *(aq)* after the formula.

OBJECTIVE 23

Table 6.10
Arrhenius Acids

Formula	Named as Binary Covalent Compound	Acid Formula	Named as Binary acid
HF or $\text{HF}(g)$	hydrogen monofluoride or hydrogen fluoride	$\text{HF}(aq)$	hydrofluoric acid
HCl or $\text{HCl}(g)$	hydrogen monochloride or hydrogen chloride	$\text{HCl}(aq)$	hydrochloric acid
HBr or $\text{HBr}(g)$	hydrogen monobromide or hydrogen bromide	$\text{HBr}(aq)$	hydrobromic acid
HI or $\text{HI}(g)$	hydrogen moniodide or hydrogen iodide	$\text{HI}(aq)$	hydriodic acid

Names and Formulas of Oxyacids

To name oxyacids, you must first be able to recognize them by the general formula $H_aX_bO_c$, with X representing an element other than hydrogen or oxygen. It will also be useful for you to know the names of the polyatomic oxyanions (Table 6.3), because many oxyacid names are derived from them. If enough H^+ ions are added to a (root)ate polyatomic ion to completely neutralize its charge, the (root)ic acid is formed (Table 6.11).

OBJECTIVE 23

- If one H^+ ion is added to *nitrate*, NO_3^- , *nitric acid*, HNO_3 , is formed.
- If two H^+ ions are added to *sulfate*, SO_4^{2-} , *sulfuric acid*, H_2SO_4 , is formed.
- If three H^+ ions are added to *phosphate*, PO_4^{3-} , *phosphoric acid*, H_3PO_4 , is formed.

Note that the whole name for sulfur, not just the root, *sulf-*, is found in the name sulfuric acid. Similarly, although the usual root for phosphorus is *phosph-*, the root *phosphor-* is used for phosphorus-containing oxyacids, as in the name *phosphoric acid*.

Table 6.11

Relationship Between (Root)ate Polyatomic Ions and (Root)ic Acids

OBJECTIVE 23

Oxyanion Formula	Oxyanion Name	Oxyacid Formula	Oxyacid Name
NO_3^-	nitrate	HNO_3	nitric acid
$C_2H_3O_2^-$	acetate	$HC_2H_3O_2$	acetic acid
SO_4^{2-}	sulfate	H_2SO_4	sulfuric acid (Note that the whole name <i>sulfur</i> is used in the oxyacid name.)
CO_3^{2-}	carbonate	H_2CO_3	carbonic acid
PO_4^{3-}	phosphate	H_3PO_4	phosphoric acid (Note that the root of phosphorus in an oxyacid name is <i>phosphor-</i> .)

EXAMPLE 6.7 - Formulas for Acids**OBJECTIVE 23**

Write the chemical formulas that correspond to the names (a) hydrobromic acid and (b) sulfuric acid.

Solution

- The name hydrobromic acid has the form of a binary acid, hydro(root)ic acid. Binary acids have the formula $HX(aq)$, so hydrobromic acid is **$HBr(aq)$** . We follow the formula with (aq) to distinguish hydrobromic acid from a pure sample of hydrogen bromide, HBr .
- Sulfuric acid is **H_2SO_4** . Sulfuric acid is a very common acid, one whose formula, H_2SO_4 , you ought to memorize. We recognize sulfuric acid as a name for an oxyacid, because it has the form (root)ic acid. You can also derive its formula from the formula for sulfate, SO_4^{2-} , by adding enough H^+ ions to neutralize the charge. Among the many uses of H_2SO_4 are the manufacture of explosives and the reprocessing of spent nuclear fuel.

EXAMPLE 6.8 - Naming Acids**OBJECTIVE 23**

Write the names that correspond to the chemical formulas (a) HNO_3 and (b) $HF(aq)$.

Solution

- The first step in writing a name from a chemical formula is to decide which type of compound the formula represents. This formula represents an oxyacid. Remember that the (root)ate polyatomic ion leads to the (root)ic acid. The name for NO_3^- is nitrate, so HNO_3 is **nitric acid**.
- The first step in writing a name from a chemical formula is to determine the type of compound the formula represents. This one, $HF(aq)$, has the form of a binary acid, $HX(aq)$, so its name is *hydro-* followed by the root of the name of the halogen, then *-ic* and *acid*: **hydrofluoric acid**. This acid is used to make chlorofluorocarbons, CFCs.

EXERCISE 6.7 - Formulas for Acids**OBJECTIVE 23**

Write the chemical formulas that correspond to the names (a) hydrofluoric acid and (b) phosphoric acid.

EXERCISE 6.8 - Naming Acids**OBJECTIVE 23**

Write the names that correspond to the chemical formulas (a) $HI(aq)$ and (b) $HC_2H_3O_2$.

6.5 Summary of Chemical Nomenclature

Perhaps at this point you are feeling confused by the many different conventions for naming different kinds of chemical compounds. Here is an overview of the guidelines for naming and writing formulas for all of the types of compounds described in this chapter.

Some names and formulas for compounds can be constructed from general rules, but others must be memorized. Table 6.12 lists some commonly encountered names and formulas that must be memorized. Check with your instructor to see which of these you need to know. Your instructor might also want to add others to the list.

Table 6.12
Compound Names and Formulas

OBJECTIVE 25

Name	Formula	Name	Formula
water	H ₂ O	ammonia	NH ₃
methane	CH ₄	ethane	C ₂ H ₆
propane	C ₃ H ₈	methanol (methyl alcohol)	CH ₃ OH
ethanol (ethyl alcohol)	C ₂ H ₅ OH	2-propanol (isopropyl alcohol)	C ₃ H ₇ OH

The general procedure for naming other compounds consists of two steps:

OBJECTIVE 25

STEP 1 Decide what type of compound the name or formula represents.

STEP 2 Apply the rules for writing the name or formula for that type of compound.

Table 6.13 on the next page summarizes the distinguishing features of different kinds of formulas and names.

There is a tutorial on the textbook's Web site that will provide practice identifying types of substances.

Table 6.13

Nomenclature for Some Types of Compounds

OBJECTIVE 24

OBJECTIVE 25

Type of Compound	General Formula	Examples	General Name	Examples
Binary covalent	A_aB_b	N_2O_5 or CO_2	(prefix unless mono)(name of first element in formula) (prefix)(root of second element)ide	dinitrogen pentoxide or carbon dioxide
Binary ionic	M_aA_b	$NaCl$ or $FeCl_3$	(name of metal) (root of nonmetal)ide or (name of metal)(Roman numeral) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = formula of polyatomic ion	Li_2HPO_4 or $CuSO_4$ or NH_4Cl or $(NH_4)_2SO_4$	(name of metal) (name of polyatomic ion) or (name of metal)(Roman numeral) (name of polyatomic ion) or ammonium (root of nonmetal)ide or ammonium (name of polyatomic ion)	lithium hydrogen phosphate or copper(II) sulfate or ammonium chloride or ammonium sulfate
Binary acid	$HX(aq)$	$HCl(aq)$	hydro(root)ic acid	hydrochloric acid
Oxyacid	$H_aX_bO_c$	HNO_3 or H_2SO_4 or H_3PO_4	(root)ic acid	nitric acid or sulfuric acid or phosphoric acid

M = symbol of metal

A and B = symbols of nonmetals

X = some element other than H or O

The letters a, b, & c represent subscripts.

There is a tutorial on the textbook's Web site that will provide practice converting between chemical names and formulas.

EXERCISE 6.9 - Formulas to Names

OBJECTIVE 25

Write the names that correspond to the following chemical formulas.

- | | | |
|--------------|------------------|-------------------|
| a. AlF_3 | d. $CaCO_3$ | g. NH_4F |
| b. PF_3 | e. $Ca(HSO_4)_2$ | h. $HCl(aq)$ |
| c. H_3PO_4 | f. $CuCl_2$ | i. $(NH_4)_3PO_4$ |

EXERCISE 6.10 - Names to Formulas

Write the chemical formulas that correspond to the following names. OBJECTIVE 25

- | | |
|---------------------------------|---------------------------|
| a. ammonium nitrate | f. hydrofluoric acid |
| b. acetic acid | g. diphosphorus tetroxide |
| c. sodium hydrogen sulfate | h. aluminum carbonate |
| d. potassium bromide | i. sulfuric acid |
| e. magnesium hydrogen phosphate | |

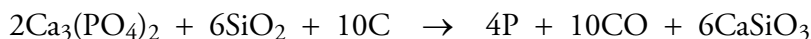
6.6 Molar Mass and Chemical Compounds

In Section 3.6, you learned how to calculate the number of atoms—expressed in moles of atoms—in a sample of an element. Molecular substances are composed of molecules, and in this section you will learn how to calculate the number of molecules, expressed in moles of molecules, in a sample of a molecular substance. Remember that, like dozen, the collective unit mole can be used to describe the number of anything. There are 6.022×10^{23} atoms in a mole of carbon atoms, there are 6.022×10^{23} electrons in a mole of electrons, and there are 6.022×10^{23} H_2O molecules in a mole of water.

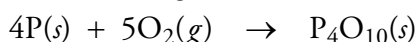
A Typical Problem

Imagine you are a chemist at a company that makes phosphoric acid, H_3PO_4 , for use in the production of fertilizers, detergents, and pharmaceuticals. The goal for your department is to produce 84.0% H_3PO_4 (and 16.0% water) in the last stage of a three-step process known as the furnace method.

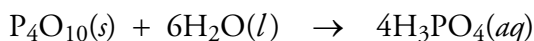
The first step in the furnace method is the extraction of phosphorus from phosphate rock by heating the rock with sand and coke to 2000 °C. The phosphate rock contains calcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$; the sand contains silicon dioxide, SiO_2 ; and coke is a carbon-rich substance that can be produced by heating coal to a high temperature. At 2000 °C, these three substances react as follows:¹



In the second step, the step on which we will focus in this chapter, the phosphorus, P, is reacted with oxygen in air to form tetraphosphorus decoxide, P_4O_{10} :



The third and final step is the reaction of P_4O_{10} with water to form phosphoric acid:



Your colleagues who are responsible for the first step, the production of pure phosphorus, estimate that they can supply you with 1.09×10^4 kg of phosphorus per day. The production manager asks you to figure out the maximum mass of P_4O_{10} that can be made from this amount of phosphorus. The tools described in this chapter, in combination with the unit analysis method, enable you to satisfy this request.

Let's begin by thinking about how unit analysis might be used to solve your problem. Your production manager is asking you to convert from amount of phosphorus, P, to amount of tetraphosphorus decoxide, P_4O_{10} . To do this, you need a conversion factor relating amount of P to amount of P_4O_{10} . The chemical formula, P_4O_{10} , provides such a conversion factor. It shows that there are four atoms of phosphorus for each



An industrial chemist must be able to calculate the amounts of reactants necessary to run an efficient reaction and predict the amount of product that will form.

¹ To avoid potential confusion, the states—(s), (l), (g), and (aq)—are often not mentioned in equations describing industrial reactions. Many industrial reactions are run at temperatures and pressures under which the states of substances differ from what would be expected at room temperatures and pressures. For example, the $\text{Ca}_3(\text{PO}_4)_2$ in the first equation on this page is a solid under normal conditions but a liquid at 2000 °C; SiO_2 is also solid under normal conditions but a glass (or semisolid) at 2000 °C.

molecule of P_4O_{10} .

$$\frac{4 \text{ atoms P}}{1 \text{ molecule}} \quad \text{or} \quad \frac{1 \text{ molecule}}{4 \text{ atoms P}}$$

But how many atoms of phosphorus are in our $1.09 \times 10^4 \text{ kg P}$? Until we know that, how can we tell how much P_4O_{10} we'll be able to produce? Unfortunately, atoms and molecules are so small and numerous that they cannot be counted directly. *We need a conversion factor that converts back and forth between any mass of the element and the number of atoms contained in that mass.* As we discovered in Section 3.6, the atomic mass of an element allows us to generate a conversion factor called molar mass that makes this possible.

If we can determine the number of phosphorus atoms in $1.09 \times 10^4 \text{ kg P}$, we can use the second conversion factor above to determine the number of molecules of P_4O_{10} . But your production manager doesn't want to know the number of P_4O_{10} molecules that you can make. She wants to know the *mass* of P_4O_{10} that can be made. That means *we also need a conversion factor that converts back and forth between any mass of the compound and the number of molecules contained in that mass.* One goal of this section is to develop conversion factors that convert between mass and number of molecules.

Molecular Mass and Molar Mass of Molecular Compounds

Because counting individual molecules is as impossible as counting individual atoms, we need to develop a way of converting back and forth between the number of moles of molecules in a sample of a molecular compound and the mass of the sample. To develop the tools necessary for the conversion between numbers of atoms and mass for elements, we had to determine the atomic mass of each element, which is the weighted average mass of the element's naturally occurring *atoms*. Likewise, for molecular compounds, our first step is to determine the **molecular mass** of the compound, which is the weighted average mass of the compound's naturally occurring *molecules*. This is found by adding the atomic masses of the atoms in each molecule.

Molecular mass = the sum of the atomic masses of each atom in the molecule

Therefore, the molecular mass of water, H_2O , is equal to the sum of the atomic masses of two hydrogen atoms and one oxygen atom, which can be found on the periodic table.

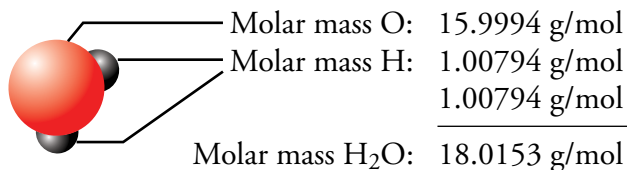
$$\text{Molecular mass H}_2\text{O} = 2(1.00794) + 15.9994 = 18.0153$$

Note that the atomic mass of each element is multiplied by the number of atoms of that element in a molecule of the compound.

The number of grams in the molar mass (grams per mole) of a molecular compound is the same as its molecular mass.

$$\text{Molar mass of a molecular compound} = \left(\frac{(\text{molecular mass}) \text{ g compound}}{1 \text{ mol compound}} \right)$$

$$\text{or, for water, } \left(\frac{18.0153 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}} \right)$$



Example 6.9 shows how a molecular mass translates into a molar mass that allows us to convert between mass of a molecular compound and number of moles of that compound.

EXAMPLE 6.9 - Molecular Mass Calculations

We have seen that the molecular compound tetraphosphorus decoxide, P₄O₁₀, is one of the substances needed for the production of phosphoric acid.

- Write a conversion factor to convert between grams of P₄O₁₀ and moles of P₄O₁₀ molecules.
- What is the mass in kilograms of 8.80×10^4 moles of tetraphosphorus decoxide, P₄O₁₀?

Solution

- The molar mass of a molecular compound, such as P₄O₁₀, provides a conversion factor that converts back and forth between grams and moles of compound. This molar mass comes from the compound's molecular mass, which is the sum of the atomic masses of the atoms in a molecule. The atomic masses of phosphorus and oxygen are found on the periodic table. The atomic mass of each element is multiplied by the number of atoms of that element in a molecule of the compound.

$$\begin{aligned} \text{Molecular mass of P}_4\text{O}_{10} &= 4(\text{atomic mass P}) + 10(\text{atomic mass O}) \\ &= 4(30.9738) + 10(15.9994) \\ &= 123.895 + 159.994 = 283.889 \end{aligned}$$

Thus there are 283.889 g P₄O₁₀ in one mole of P₄O₁₀.

$$\left(\frac{283.889 \text{ g P}_4\text{O}_{10}}{1 \text{ mol P}_4\text{O}_{10}} \right)$$

$$\text{b. } ? \text{ kg P}_4\text{O}_{10} = 8.80 \times 10^4 \cancel{\text{ mol P}_4\text{O}_{10}} \left(\frac{283.889 \cancel{\text{ g P}_4\text{O}_{10}}}{1 \cancel{\text{ mol P}_4\text{O}_{10}}} \right) \left(\frac{1 \text{ kg}}{10^3 \cancel{\text{ g}}} \right) = 2.50 \times 10^4 \text{ kg P}_4\text{O}_{10}$$

EXERCISE 6.11 - Molecular Mass Calculations

A typical glass of wine contains about 16 g of ethanol, C₂H₅OH.

- What is the molecular mass of C₂H₅OH?
- What is the mass of one mole of C₂H₅OH?
- Write a conversion factor that will convert between mass and moles of C₂H₅OH.
- How many moles of ethanol are in 16 grams of C₂H₅OH?
- What is the volume in milliliters of 1.0 mole of pure C₂H₅OH? (The density of ethanol is 0.7893 g/mL.)

OBJECTIVE 26

OBJECTIVE 27

OBJECTIVE 28

OBJECTIVE 26

OBJECTIVE 27

OBJECTIVE 28

Ionic Compounds, Formula Units, and Formula Mass

OBJECTIVE 29

The chemist also needs to be able to convert between mass and moles for ionic compounds. The calculations are the same as for molecular compounds, but some of the terminology is different. Remember that solid ionic compounds and molecular compounds differ in the way their particles are organized and held together. Water, a molecular substance, is composed of discrete H_2O molecules, each of which contains two hydrogen atoms and one oxygen atom. The ionic compound sodium chloride, NaCl , does not contain separate molecules. Each sodium ion is surrounded by six chloride ions, and each chloride ion is surrounded by six sodium ions. There are no sodium-chlorine atom pairs that belong together, separate from the other parts of the crystal. For this reason, we avoid using the term *molecule* when referring to an ionic compound. (You might want to review Sections 5.3 and 5.4, which describe the structure of molecular and ionic compounds.)

OBJECTIVE 30

It is still useful to have a term *like* molecule to use when describing the composition of ionic compounds. In this text, the term *formula unit* will be used to describe ionic compounds in situations where *molecule* is used to describe molecular substances. A **formula unit** of a substance is the group represented by the substance's chemical formula, that is, a group containing the kinds and numbers of atoms or ions listed in the chemical formula. *Formula unit* is a general term that can be used in reference to elements, molecular compounds, or ionic compounds. One formula unit of the noble gas neon, Ne , contains one neon atom. In this case, the formula unit is an atom. One formula unit of water, H_2O , contains two hydrogen atoms and one oxygen atom. In this case, the formula unit is a molecule. One formula unit of ammonium chloride, NH_4Cl , contains one ammonium ion and one chloride ion—or one nitrogen atom, four hydrogen atoms, and one chloride ion (Figure 6.8).

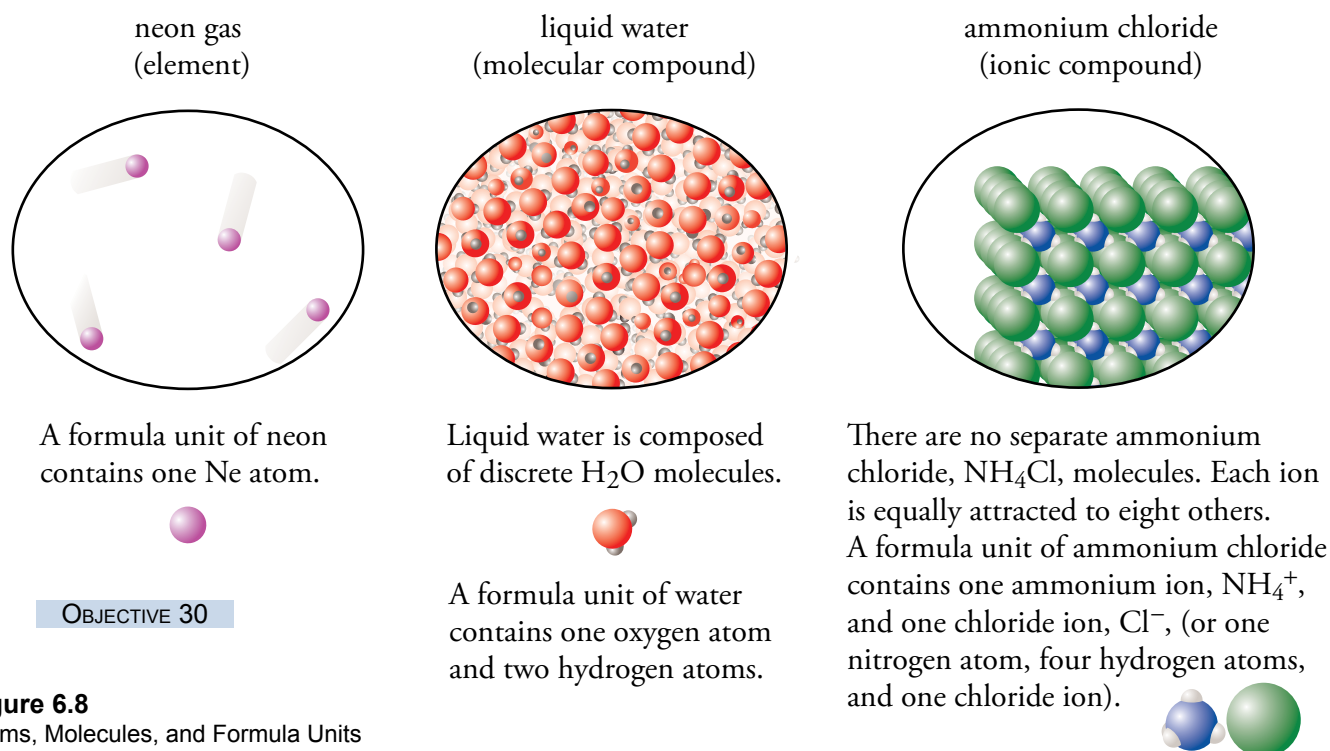


Figure 6.8
Atoms, Molecules, and Formula Units

A sample of an element is often described in terms of the number of atoms it contains, a sample of a molecular substance can be described in terms of the number of molecules it contains, and a sample of an ionic compound is often described in terms of the number of formula units it contains. One mole of carbon contains 6.022×10^{23} carbon atoms, one mole of water contains 6.022×10^{23} molecules, and one mole of sodium chloride contains 6.022×10^{23} NaCl formula units.

As we saw with mass and moles of elements and molecular compounds, it is important to be able to convert between mass and moles of ionic substances. The development of the tools for this conversion starts with the determination of the **formula mass**, which is the weighted average of the masses of the naturally occurring formula units of the substance. (It is analogous to the atomic mass for an element and the molecular mass for a molecular substance.)

Formula mass = the sum of the atomic masses of each atom in a formula unit

OBJECTIVE 31

The formula mass of sodium chloride is equal to the sum of the atomic masses of sodium and chlorine, which can be found on the periodic table.

$$\text{Formula mass NaCl} = 22.9898 + 35.4527 = 58.4425$$

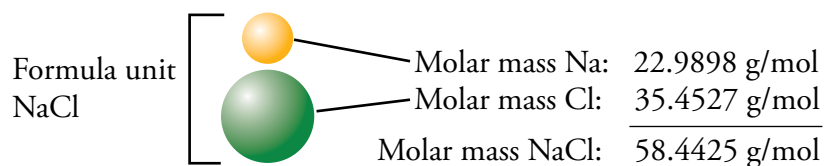
Formula mass, like *formula unit*, is a general term. The atomic mass of carbon, C, could also be called its formula mass. The molecular mass of water, H₂O, could also be called water's formula mass.

The number of grams in the molar mass (grams per mole) of any ionic compound is the same as its formula mass.

$$\text{Molar mass of an ionic compound} = \left(\frac{(\text{formula mass}) \text{ g compound}}{1 \text{ mol compound}} \right)$$

OBJECTIVE 32

$$\text{or, for sodium chloride, } \left(\frac{58.4425 \text{ g NaCl}}{1 \text{ mol NaCl}} \right)$$



EXAMPLE 6.10 - Formula Mass Calculations

OBJECTIVE 31

OBJECTIVE 32

OBJECTIVE 33

Water from coal mines is contaminated with sulfuric acid that forms when water reacts with iron(III) sulfate, $\text{Fe}_2(\text{SO}_4)_3$.

- Write a conversion factor to convert between grams of the ionic compound iron(III) sulfate and moles of $\text{Fe}_2(\text{SO}_4)_3$ formula units.
- Calculate how many moles of $\text{Fe}_2(\text{SO}_4)_3$ are in 2.672 lb of $\text{Fe}_2(\text{SO}_4)_3$.

Solution

- The molar mass, which provides a conversion factor for converting back and forth between grams and moles of an ionic compound, comes from the compound's formula mass.

$$\begin{aligned} \text{Formula mass of } \text{Fe}_2(\text{SO}_4)_3 &= 2(\text{atomic mass Fe}) + 3(\text{atomic mass S}) + 12(\text{atomic mass O}) \\ &= 2(55.845) + 3(32.066) + 12(15.9994) \\ &= 111.69 + 96.198 + 191.993 = 399.88 \end{aligned}$$

Thus the conversion factor that converts back and forth between grams moles of iron(III) sulfate is

$$\left(\frac{399.88 \text{ g } \text{Fe}_2(\text{SO}_4)_3}{1 \text{ mol } \text{Fe}_2(\text{SO}_4)_3} \right)$$

$$\begin{aligned} \text{b. } ? \text{ mol } \text{Fe}_2(\text{SO}_4)_3 &= 2.672 \text{ lb } \text{Fe}_2(\text{SO}_4)_3 \left(\frac{453.6 \text{ g}}{1 \text{ lb}} \right) \left(\frac{1 \text{ mol } \text{Fe}_2(\text{SO}_4)_3}{399.88 \text{ g } \text{Fe}_2(\text{SO}_4)_3} \right) \\ &= 3.031 \text{ mol } \text{Fe}_2(\text{SO}_4)_3 \end{aligned}$$

EXERCISE 6.12 - Formula Mass Calculations

OBJECTIVE 31

OBJECTIVE 32

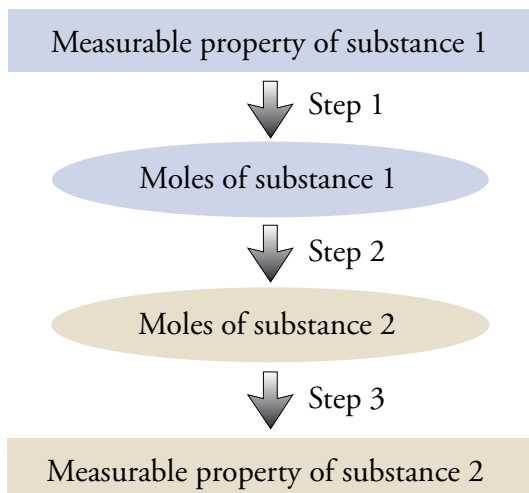
OBJECTIVE 33

A quarter teaspoon of a typical baking powder contains about 0.4 g of sodium hydrogen carbonate, NaHCO_3 .

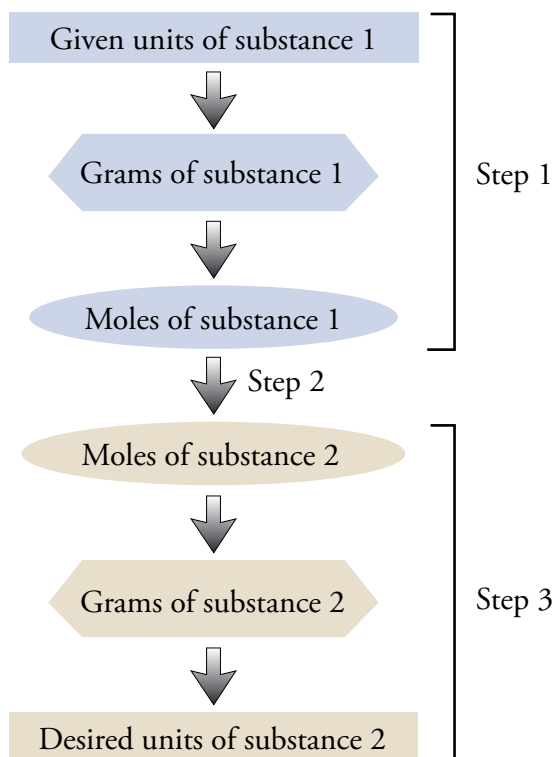
- Calculate the formula mass of sodium hydrogen carbonate.
- What is the mass in grams of one mole of NaHCO_3 ?
- Write a conversion factor to convert between mass and moles of NaHCO_3 .
- How many moles of NaHCO_3 are in 0.4 g of NaHCO_3 ?

6.7 Relationships Between Masses of Elements and Compounds

Many of the conversions you will be doing in chemistry require you to convert amount of one substance (substance 1) to amount of another substance (substance 2). Such conversions can be done in three basic steps:



Mass is often the most easily measured property, and we now know how to convert between mass in grams and moles of a substance using the substance's molar mass. The solutions to many problems will therefore follow these steps:



To complete these steps, we need conversion factors that convert between moles of one substance and moles of another. For example, we might want to convert between moles of an element and moles of a compound containing that element. We obtain this conversion factor from the compound's chemical formula. For example, the formula

for hexane, C_6H_{14} , tells us that each hexane molecule contains six atoms of carbon and fourteen atoms of hydrogen. A dozen C_6H_{14} molecules contain six dozen atoms of carbon and fourteen dozen atoms of hydrogen, and one mole of C_6H_{14} contains six moles of carbon atoms and fourteen moles of hydrogen atoms. These relationships lead to the following conversion factors:

$$\left(\frac{6 \text{ mol C}}{1 \text{ mol } C_6H_{14}} \right) \quad \text{and} \quad \left(\frac{14 \text{ mol H}}{1 \text{ mol } C_6H_{14}} \right)$$

One mole of the oxygen found in air, O_2 , contains 6.022×10^{23} molecules and 1.204×10^{24} (two times 6.022×10^{23}) oxygen atoms. There are two moles of oxygen atoms in one mole of oxygen molecules.

$$\left(\frac{2 \text{ mol O}}{1 \text{ mol } O_2} \right)$$

Similarly, we can use ionic formulas to generate conversion factors that convert between moles of atoms of each element in an ionic compound and moles of compound. For example, the formula for calcium nitrate, $Ca(NO_3)_2$, yields the following conversion factors.

$$\left(\frac{1 \text{ mol Ca}}{1 \text{ mol } Ca(NO_3)_2} \right) \quad \text{and} \quad \left(\frac{2 \text{ mol N}}{1 \text{ mol } Ca(NO_3)_2} \right) \quad \text{and} \quad \left(\frac{6 \text{ mol O}}{1 \text{ mol } Ca(NO_3)_2} \right)$$

The collective unit of mole can also be used to describe ions. Thus the following conversion factors also come from the formula of calcium nitrate, $Ca(NO_3)_2$.

$$\left(\frac{1 \text{ mol } Ca^{2+}}{1 \text{ mol } Ca(NO_3)_2} \right) \quad \text{and} \quad \left(\frac{2 \text{ mol } NO_3^-}{1 \text{ mol } Ca(NO_3)_2} \right)$$

EXAMPLE 6.11 - Molar Ratios of Element to Compound

OBJECTIVE 34

OBJECTIVE 35

Consider the molecular compound tetraphosphorus decoxide, P_4O_{10} , and the ionic compound iron(III) sulfate, $Fe_2(SO_4)_3$.

- Write a conversion factor that converts between moles of phosphorus and moles of P_4O_{10} .
- Write a conversion factor that converts between moles of iron and moles of iron(III) sulfate.
- How many moles of sulfate are in one mole of iron(III) sulfate?

Solution

- The formula P_4O_{10} shows that there are 4 atoms of phosphorus per molecule of P_4O_{10} or 4 moles of phosphorus per mole of P_4O_{10} .

$$\left(\frac{4 \text{ mol P}}{1 \text{ mol } P_4O_{10}} \right)$$

- $\left(\frac{2 \text{ mol Fe}}{1 \text{ mol } Fe_2(SO_4)_3} \right)$

- There are **three moles of SO_4^{2-}** in one mole of $Fe_2(SO_4)_3$.

EXERCISE 6.13 - Molar Ratios of Element to Compound

Find the requested conversion factors.

- Write a conversion factor that converts between moles of hydrogen and moles of C_2H_5OH .
- Write a conversion factor that converts between moles of oxygen and moles of $NaHCO_3$.
- How many moles of hydrogen carbonate ions, HCO_3^- , are in one mole of $NaHCO_3$?

OBJECTIVE 34

OBJECTIVE 35

We are now ready to work the “typical problem” presented in Section 6.6.

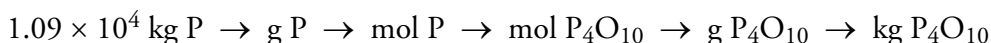
EXAMPLE 6.12 - Molecular Mass Calculations

What is the maximum mass of tetraphosphorus decoxide, P_4O_{10} , that could be produced from 1.09×10^4 kg of phosphorus, P?

OBJECTIVE 36

Solution

The steps for this conversion are



Note that these follow the general steps we have been discussing.

To find a conversion factor that converts from moles of phosphorus to moles of P_4O_{10} , we look at the formula for tetraphosphorus decoxide, P_4O_{10} . It shows that each molecule of tetraphosphorus decoxide contains four atoms of phosphorus. By extension, one dozen P_4O_{10} molecules contains four dozen P atoms, and one mole of P_4O_{10} (6.022×10^{23} P_4O_{10} molecules) contains four moles of phosphorus (4 times 6.022×10^{23} P atoms). Thus the formula P_4O_{10} provides us with the following conversion factor:

$$\left(\frac{1 \text{ mol P}_4\text{O}_{10}}{4 \text{ mol P}} \right)$$

The molar mass of phosphorus can be used to convert grams of phosphorus to moles of phosphorus, and the molar mass of P_4O_{10} can be used to convert moles of P_4O_{10} to grams. Conversions of kilograms to grams and of grams to kilograms complete our setup.

$$\begin{aligned}
 ? \text{ kg P}_4\text{O}_{10} &= 1.09 \times 10^4 \text{ kg P} \left(\frac{10^3 \text{ g}}{1 \text{ kg}} \right) \left(\frac{1 \text{ mol P}}{30.9738 \text{ g P}} \right) \left(\frac{1 \text{ mol P}_4\text{O}_{10}}{4 \text{ mol P}} \right) \left(\frac{283.889 \text{ g P}_4\text{O}_{10}}{1 \text{ mol P}_4\text{O}_{10}} \right) \left(\frac{1 \text{ kg}}{10^3 \text{ g}} \right) \\
 &= 2.50 \times 10^4 \text{ kg P}_4\text{O}_{10}
 \end{aligned}$$

Converts given mass unit into grams. Converts moles of element into moles of compound. Converts grams into desired mass unit.

Converts grams of element into moles. Converts moles of compound into grams.

Sample Study Sheet 6.1

Converting Between Mass of Element and Mass of Compound Containing the Element

OBJECTIVE 36

TIP-OFF When you analyze the type of unit you have and the type of unit you want, you recognize that you are converting between a unit associated with an element and a unit associated with a compound containing that element.

GENERAL STEPS The following general procedure is summarized in Figure 6.9.

- **Convert the given unit to moles of the first substance.**

This step often requires converting the given unit into grams, after which the grams can be converted into moles using the molar mass of the substance.

- **Convert moles of the first substance into moles of the second substance using the molar ratio derived from the formula for the compound.**

You either convert from moles of element to moles of compound or moles of compound to moles of element.

- **Convert moles of the second substance to the desired units of the second substance.**

This step requires converting moles of the second substance into grams of the second substance using the molar mass of the second substance, after which the grams can be converted to the specific units that you want.

EXAMPLE See Example 6.12.

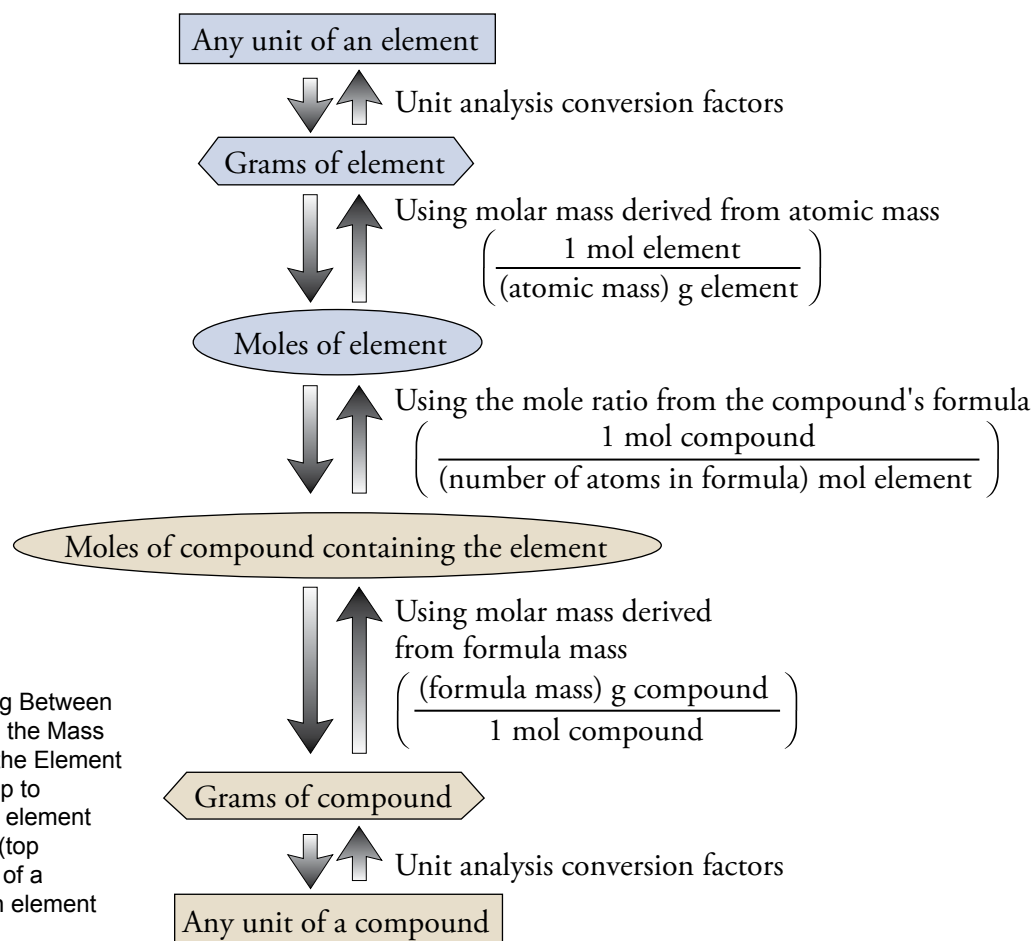


Figure 6.9

General Steps for Converting Between the Mass of an Element and the Mass of a Compound Containing the Element
 The calculation can be set up to convert from the mass of an element to the mass of a compound (top to bottom) or from the mass of a compound to the mass of an element (bottom to top).

EXERCISE 6.14 - Molar Mass Calculations

Disulfur dichloride, S_2Cl_2 , is used in vulcanizing rubber and hardening soft woods. It can be made from the reaction of pure sulfur with chlorine gas. What is the mass of S_2Cl_2 that contains 123.8 g S?

OBJECTIVE 36

EXERCISE 6.15 - Molar Mass Calculations

Vanadium metal, used as a component of steel and to catalyze various industrial reactions, is produced from the reaction of vanadium(V) oxide, V_2O_5 , and calcium metal. What is the mass in kilograms of vanadium in 2.3 kilograms of V_2O_5 ?

OBJECTIVE 36

The skills developed in this chapter can be used to calculate the percentage of each element in a compound. See how this is done at the textbook's Web site.

6.8 Determination of Empirical and Molecular Formulas

By this point in your study of chemistry, you have seen many chemical formulas. Have you wondered where they come from or how we know the relative numbers of atoms of each element in a compound? This section describes some of the ways chemists determine chemical formulas from experimental data.

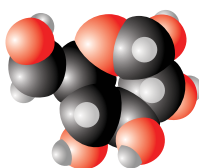
Before beginning, we need to understand the distinction between two types of chemical formulas, empirical formulas and molecular formulas. When the subscripts in a chemical formula represent the simplest ratio of the kinds of atoms in the compound, the formula is called an **empirical formula**. Most ionic compounds are described with empirical formulas. For example, chromium(III) oxide's formula, Cr_2O_3 , is an empirical formula. The compound contains two chromium atoms for every three oxide atoms, and there is no lower ratio representing these relative amounts.

Molecular compounds are described with molecular formulas. A **molecular formula** describes the actual numbers of atoms of each element in a molecule. Some molecular formulas are also empirical formulas. For example, water molecules are composed of two hydrogen atoms and one oxygen atom, so water's molecular formula is H_2O . Because this formula represents the simplest ratio of hydrogen atoms to oxygen atoms in water, it is also an empirical formula.

Many molecular formulas are not empirical formulas. Hydrogen peroxide molecules contain two hydrogen atoms and two oxygen atoms, so hydrogen peroxide's molecular formula is H_2O_2 . The empirical formula of hydrogen peroxide is HO. The molecular formula for glucose is $C_6H_{12}O_6$, and its empirical formula is CH_2O .



hydrogen peroxide
molecular formula, H_2O_2 ,
empirical formula, HO



glucose
molecular formula, $C_6H_{12}O_6$,
empirical formula, CH_2O

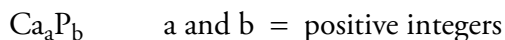
Determination of Empirical Formulas

If we know the relative mass or the mass percentage of each element in a compound, we can determine the compound's empirical formula. The general procedure is summarized in Study Sheet 6.2, but before we look at it, let's reason it out using a substance that is sometimes called photophor, an ingredient in signal fires, torpedoes, fireworks, and rodent poison.



This is a "signal pistol" or flare gun.

The subscripts in an empirical formula are positive integers representing the simplest ratio of the atoms of each element in the formula. For now, we can describe the empirical formula for photophor in the following way:



(Remember that in binary compounds containing a metal and a nonmetal, the symbol for the metal is listed first.) The a and b in the formula above represent the subscripts in the empirical formula. For every a atoms of calcium, there are b atoms of phosphorus, or for every a moles of Ca, there are b moles of P. Thus the ratio of a to b describes the molar ratio of these elements in the compound.

If we can determine the number of moles of each element in any amount of a substance, we can calculate the molar ratio of these elements in the compound, which can then be simplified to the positive integers that represent the simplest molar ratio. We found in Sections 3.6 and 6.6 that we can calculate moles of a substance from grams. Thus one path to determining the empirical formula for a compound is:

Grams of each element in a specific amount of compound



Moles of each element in that amount of compound



Molar ratio of the elements



Simplest molar ratio of the elements

OBJECTIVE 37

Imagine that a sample of photophor has been analyzed and found to contain 12.368 g calcium and 6.358 g phosphorus. These masses can be converted to moles using the molar masses of the elements.

$$? \text{ mol Ca} = 12.368 \text{ g Ca} \left(\frac{1 \text{ mol Ca}}{40.078 \text{ g Ca}} \right) = 0.30860 \text{ mol Ca}$$

$$? \text{ mol P} = 6.358 \text{ g P} \left(\frac{1 \text{ mol P}}{30.9738 \text{ g P}} \right) = 0.2053 \text{ mol P}$$

The molar ratio of Ca:P is therefore 0.30860 moles of calcium to 0.2053 moles of phosphorus. We simplify it to the integers that represent the simplest molar ratio using

the following steps.

- Divide each mole value by the smallest mole value, and round the answer to the nearest positive integer or common mixed fraction. (A mixed fraction contains an integer and a fraction. For example, $2\frac{1}{2}$ is a mixed fraction.)
- If one of the values is a fraction, multiply all the values by the denominator of the fraction.

In this case, we divide the mole values for Ca and P by 0.2053. This step always leads to 1 mole for the smallest value. We then round the other mole values to positive integers or common mixed fractions.

$$\frac{0.30860 \text{ mol Ca}}{0.2053} = 1.503 \text{ mol Ca} \approx 1\frac{1}{2} \text{ mol Ca}$$

$$\frac{0.2053 \text{ mol P}}{0.2053} = 1 \text{ mol P}$$

(The mole value for calcium has been rounded off from 1.503 to $1\frac{1}{2}$.)

We will restrict the examples in this text to compounds with relatively simple formulas. Thus, when you work the end-of-chapter problems, the values you will obtain at this stage will always be within 0.02 of a positive integer or a common mixed fraction, and the denominators for your fractions will be 4 or smaller.

To complete the determination of the empirical formula of phosphorus, we multiply each mole value by 2 to get rid of the fraction:

$$1\frac{1}{2} \text{ mol Ca} \times 2 = 3 \text{ mol Ca}$$

$$1 \text{ mol P} \times 2 = 2 \text{ mol P}$$

Our empirical formula is Ca_3P_2 , which represents calcium phosphide. Sample Study Sheet 6.2 summarizes these steps.

TIP-OFF You wish to calculate an empirical formula.

GENERAL STEPS The following procedure is summarized in Figure 6.10.

1. If you are not given the mass of each element in grams, convert the data you *are* given to mass of each element in grams.
 - In some cases, this can be done with simple unit conversions. For example, you may be given pounds or milligrams, which can be converted to grams using unit analysis.
 - Sometimes you are given the percentage of each element in the compound. If so, assume that you have 100 g of compound, and change the percentages to grams (see Example 6.13).
2. Convert grams of each element to moles by dividing by the atomic mass of the element.
3. Divide each mole value by the smallest mole value, and round your answers to positive integers or common mixed fractions.
4. If you have a fraction after the last step, multiply all the mole values by the denominator of the fraction.
5. The resulting mole values represent the subscripts in the empirical formula.

EXAMPLE See Example 6.13.

Sample Study Sheet 6.2

Calculating Empirical Formulas

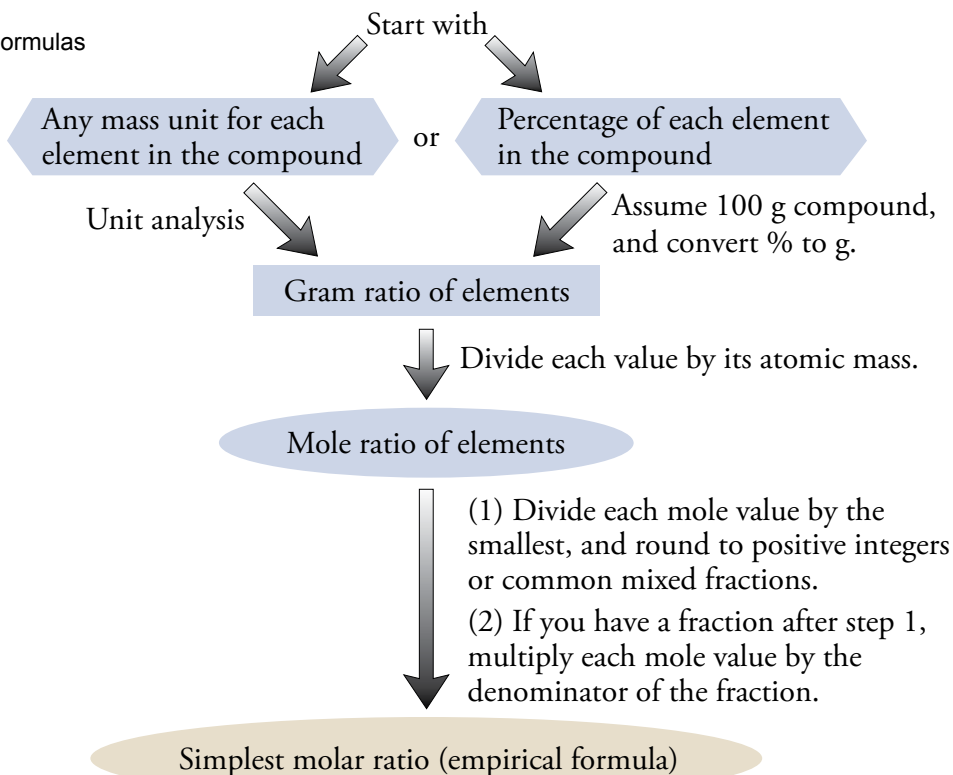
OBJECTIVE 37

OBJECTIVE 38

Figure 6.10
Calculating Empirical Formulas

OBJECTIVE 37

OBJECTIVE 38



EXAMPLE 6.13 - Calculating an Empirical Formula from the Percentage of Each Element

OBJECTIVE 38

An ionic compound sometimes called pearl ash is used to make special glass for color TV tubes. A sample of this compound is analyzed and found to contain 56.50% potassium, 8.75% carbon, and 34.75% oxygen. What is the empirical formula for this compound? What is its chemical name?

Solution

If we assume that we have a 100-g sample, the conversion from percentages to a gram ratio becomes very simple. We just change each “%” to “g”. Thus 100 g of pearl ash would contain 56.50 g K, 8.75 g C, and 34.75 g O.

Now we can proceed with the steps described in Sample Study Sheet 6.2 to convert from grams of each element to the empirical formula.

$$? \text{ mol K} = 56.50 \text{ g K} \left(\frac{1 \text{ mol K}}{39.0983 \text{ g K}} \right) = 1.445 \text{ mol K} \div 0.728 = 1.985 \text{ mol K} \approx 2 \text{ mol K}$$

$$? \text{ mol C} = 8.75 \text{ g C} \left(\frac{1 \text{ mol C}}{12.011 \text{ g C}} \right) = 0.728 \text{ mol C} \div 0.728 = 1 \text{ mol C}$$

$$? \text{ mol O} = 34.75 \text{ g O} \left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}} \right) = 2.172 \text{ mol O} \div 0.728 = 2.984 \text{ mol O} \approx 3 \text{ mol O}$$

The empirical formula is K_2CO_3 , which is potassium carbonate.

EXERCISE 6.16 - Calculating an Empirical Formula

Bismuth ore, often called bismuth glance, contains an ionic compound consisting of the elements bismuth and sulfur. A sample of the pure compound is found to contain 32.516 g Bi and 7.484 g S. What is the empirical formula for this compound? What is its name?

OBJECTIVE 37

EXERCISE 6.17 - Calculating an Empirical Formula

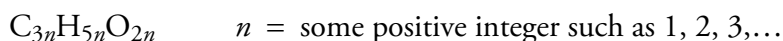
An ionic compound used in the brewing industry to clean casks and vats and in the wine industry to kill undesirable yeasts and bacteria is composed of 35.172% potassium, 28.846% sulfur, and 35.982% oxygen. What is the empirical formula for this compound?

OBJECTIVE 38

Converting Empirical Formulas to Molecular Formulas

To see how empirical formulas can be converted to molecular formulas, let's consider an analysis of adipic acid, which is one of the substances used to make Nylon-66. (Nylon-66, originally used as a replacement for silk in women's stockings, was invented in 1935 and was produced commercially starting in 1940.) Experiment shows that adipic acid is 49.31% carbon, 6.90% hydrogen, and 43.79% oxygen, which converts to an empirical formula of $C_3H_5O_2$. From a separate experiment, the molecular mass of adipic acid is found to be 146.144. We can determine the molecular formula for adipic acid from this data.

The subscripts in a molecular formula are always whole-number multiples of the subscripts in the empirical formula. The molecular formula for adipic acid can therefore be described in the following way.



The n can be calculated from adipic acid's molecular mass and its empirical formula mass. A substance's empirical formula mass can be calculated from the subscripts in its empirical formula and the atomic masses of the elements. The empirical formula mass of adipic acid is

$$\text{Empirical formula mass} = 3(12.011) + 5(1.00794) + 2(15.9994) = 73.072$$

Because the subscripts in the molecular formula are always a positive integer multiple of the subscripts in the empirical formula, the molecular mass is always equal to a positive integer multiple of the empirical formula mass.

$$\text{Molecular mass} = n (\text{empirical formula mass})$$

$$n = \text{some positive integer, such as } 1, 2, 3, \dots$$

Therefore, we can calculate n by dividing the molecular mass by the empirical formula mass.

$$n = \frac{\text{molecular mass}}{\text{empirical formula mass}}$$

For our example, the given molecular mass of $C_3H_5O_2$ divided by the empirical formula mass is:

$$n = \frac{\text{molecular mass}}{\text{empirical formula mass}} = \frac{146.144}{73.072} = 2$$

Once you have calculated n , you can determine the molecular formula by multiplying each of the subscripts in the empirical formula by n . This gives a molecular formula for adipic acid of $C_{3(2)}H_{5(2)}O_{2(2)}$ or $C_6H_{10}O_4$ (see Special Topic 6.2 *Green Chemistry—Making Chemicals from Safer Reactants*).

SPECIAL TOPIC 6.2 Green Chemistry— Making Chemicals from Safer Reactants

Because benzene, C_6H_6 , is a readily available and inexpensive substance that can be easily converted into many different substances, it is a common industrial starting material for making a wide range of important chemicals. A problem with using benzene, however, is that it is known to cause cancer and to be toxic in other ways as well. Thus there is strong incentive to find alternative methods for making chemicals that in the past have been made from benzene.

You discovered in this section that adipic acid is used to make nylon, but it is also used to make paint, synthetic lubricants, and plasticizers (substances that make plastics more flexible). Adipic acid is one of the important industrial chemicals conventionally produced from benzene, but recently a new process has been developed that forms adipic acid from the sugar glucose, which is much safer, instead of benzene. If you were a worker in a chemical plant making adipic acid, you would certainly prefer working with sugar instead of benzene.



Can nylon be made from sugar?

TIP-OFF You want to calculate a molecular formula and have been given the molecular mass of the substance and either the empirical formula or enough data to calculate the empirical formula.

GENERAL STEPS The following procedure is summarized in Figure 6.11.

- If necessary, calculate the empirical formula of the compound from the data given. (See Sample Study Sheet 6.2: Calculating Empirical Formulas.)
- Divide the molecular mass by the empirical formula mass.

$$n = \frac{\text{molecular mass}}{\text{empirical formula mass}}$$

- Multiply each of the subscripts in the empirical formula by n to get the molecular formula.

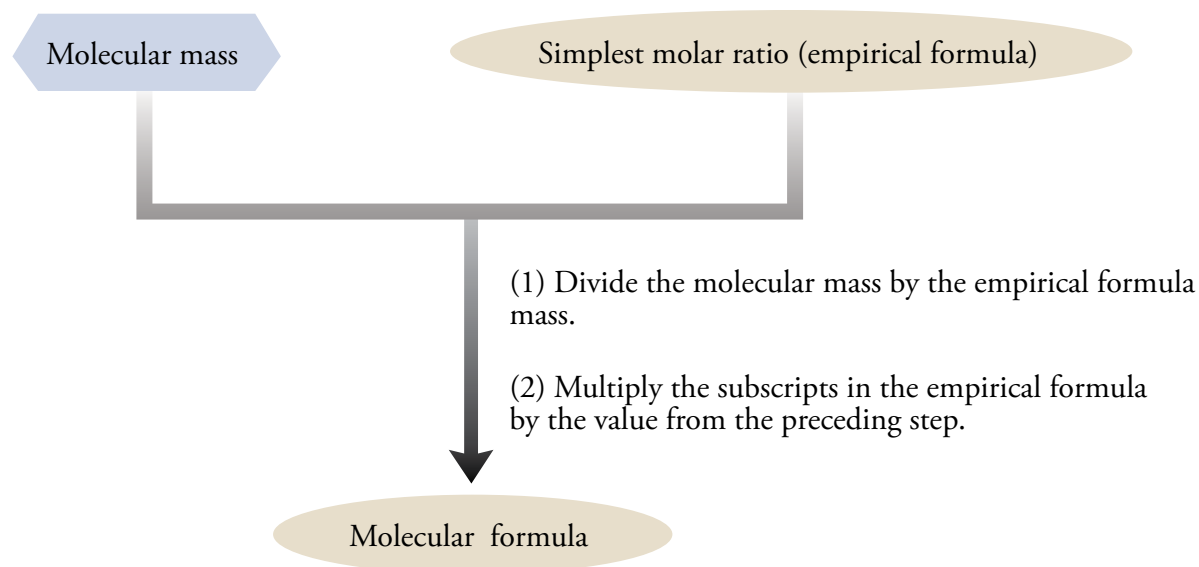
EXAMPLE See Example 6.14.

Sample Study Sheet 6.3 Calculating Molecular Formulas

OBJECTIVE 39

OBJECTIVE 39

Figure 6.11
Calculating Molecular Formulas



EXAMPLE 6.14 - Calculating a Molecular Formula Using the Percentage of Each Element in a Compound

OBJECTIVE 38

OBJECTIVE 39

A chemical called BD (or sometimes BDO), which is used in the synthesis of Spandex, has controversial uses as well. In 1999, it was added to products that claimed to stimulate the body's immune system, reduce tension, heighten sexual experience, repair muscle tissue, and cure insomnia (see Special Topic 6.3: *Safe and Effective?*). The FDA seized these products because of suspicions that BD caused at least three deaths and many severe adverse reactions. BD is composed of 53.31% carbon, 11.18% hydrogen, and 35.51% oxygen and has a molecular mass of 90.122. What is its molecular formula?

Solution

$$? \text{ mol C} = 53.31 \text{ g C} \left(\frac{1 \text{ mol C}}{12.011 \text{ g C}} \right) = 4.438 \text{ mol C} \div 2.219 = 2 \text{ mol C}$$

$$? \text{ mol H} = 11.18 \text{ g H} \left(\frac{1 \text{ mol H}}{1.00794 \text{ g H}} \right) = 11.09 \text{ mol H} \div 2.219 \approx 5 \text{ mol H}$$

$$? \text{ mol O} = 35.51 \text{ g O} \left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}} \right) = 2.219 \text{ mol O} \div 2.219 = 1 \text{ mol O}$$

$$\text{Empirical formula: } \text{C}_2\text{H}_5\text{O} \quad n = \frac{\text{molecular mass}}{\text{empirical formula mass}} = \frac{90.122}{45.061} = 2$$

Molecular formula: $\text{C}_4\text{H}_{10}\text{O}_2$

EXERCISE 6.18 - Calculating a Molecular Formula Using the Percentage of Each Element in a Compound

OBJECTIVE 38

OBJECTIVE 39

Compounds called polychlorinated biphenyls (PCBs) have structures similar to chlorinated insecticides such as DDT. They have been used in the past for a variety of purposes, but because they have been identified as serious pollutants, their only legal use today is as insulating fluids in electrical transformers. One PCB is composed of 39.94% carbon, 1.12% hydrogen, and 58.94% chlorine and has a molecular mass of 360.88. What is its molecular formula?

Empirical and molecular formulas can be derived from a process called combustion analysis. You can learn about this process at the textbook's Web site.

SPECIAL TOPIC 6.3 Safe and Effective?

The public is continually bombarded with claims for new products containing “miracle” ingredients “guaranteed” to improve our health, strength, happiness, and sex life and to give us a good night’s sleep. In 1999, such claims were made on behalf of products with names such as Revitalize Plus, Serenity, Enliven, and Thunder Nectar, all of which contained a substance called 1,4-butanediol (BD). They were marketed on the Internet, sold in health food stores, and advertised in muscle-building magazines.

The claims were enticing, but according to the U.S. Food and Drug Administration (FDA), they were also unfounded. Perhaps more importantly, the FDA decided that this unapproved new drug could cause dangerously low respiratory rates, unconsciousness, seizures, and even death. Because the FDA connected BD with at least three deaths and many severe adverse reactions, they designated it a Class I health hazard, which means “its use could pose potentially life-threatening risks.” The FDA seized products containing BD to prevent their causing further illness and death. Advocates of the drug submitted anecdotal evidence to show that many people have taken the substance without ill effects. As of this writing, no one knows with certainty which side is correct.

Because humans are very complex chemical factories, the positive and negative effects of a drug can be difficult to determine. To some extent, they depend on each person’s unique biochemistry, as well as on interactions with other chemicals that may be present in the body. For example, the effects of BD are thought to be enhanced by alcohol and other depressants, so if an individual takes one of the “party drugs” containing BD (drugs with names like Cherry fX Bombs) and drinks

too much beer, the combined depressant effect can lead to loss of consciousness, coma, and perhaps death. To minimize the uncertainties associated with individual reactions to a drug, scientists run carefully controlled tests, first on animals and only much later on humans. Until these tests are done for BD, its true effects (both positive and negative) cannot be known with confidence.

So, how do you decide whether to consume a product containing a chemical like BD? Let’s consider a student named Fred who is surfing the Internet for ideas about how to relax before his final exams. One site he finds describes a product guaranteed to calm his nerves and recharge his immune system. The product seems to contain a lot of good ingredients, such as vitamins and minerals, but the most important component is tetramethylene glycol. The description of how the substance works is written in unfamiliar terminology, but Fred thinks he gets the gist, and it seems to make sense. Fortunately, he passes up the opportunity to buy this product and takes a walk in the woods to calm his nerves instead. He’s never heard of the product’s distributor, he knows that false and unproven advertising claims are often cloaked in pseudoscientific explanations, and he remembers reading in his chemistry book that tetramethylene glycol is another name for 1,4-butanediol (BD), a potentially dangerous substance.

The important points in this story are that it is best to stick to products from known manufacturers who have a reputation for carefully screening their ingredients; to be skeptical of claims made in advertising and on the Internet; and to keep yourself educated about substances that are suspected of being harmful. When in doubt, ask your doctor. It’s part of his or her job to know about the safety and effectiveness of health products.

Chapter Glossary

Binary ionic compound An ionic compound whose formula contains one symbol for a metal and one symbol for a nonmetal.

Binary covalent compound A compound that consists of two nonmetallic elements.

Hydronium ion H_3O^+

Arrhenius acid According to the Arrhenius theory, any substance that generates hydronium ions, H_3O^+ , when added to water.

Acidic solution A solution with a significant concentration of hydronium ions, H_3O^+ .

Binary acid Substances that have the general formula of $\text{HX}(aq)$, where X is one of the first four halogens: $\text{HF}(aq)$, $\text{HCl}(aq)$, $\text{HBr}(aq)$, and $\text{HI}(aq)$.

Oxyacids (or oxoacids) Molecular substances that have the general formula $\text{H}_a\text{X}_b\text{O}_c$. In other words, they contain hydrogen, oxygen, and one other element represented by X; the a , b , and c represent subscripts.

Monoprotic acid An acid that donates one hydrogen ion per molecule in a reaction.

Polyprotic acid An acid that can donate more than one hydrogen ion per molecule in a reaction.

Diprotic acid An acid that can donate two hydrogen ions per molecule in a reaction.

Triprotic acid An acid that can donate three hydrogen ions per molecule in a reaction.

Strong acid An acid that donates its H^+ ions to water in a reaction that goes completely to products. Such a compound produces close to one H_3O^+ ion in solution for each acid molecule dissolved in water.

Weak acid A substance that is incompletely ionized in water due to the reversibility of the reaction that forms hydronium ions, H_3O^+ , in water. Weak acids yield significantly less than one H_3O^+ ion in solution for each acid molecule dissolved in water.

Reversible reaction A reaction in which the reactants are constantly forming products and, at the same time, the products are reforming the reactants.

Completion Reaction A chemical reaction that is not significantly reversible.

Molecular mass The weighted average of the masses of the naturally occurring molecules of a molecular substance. It is the sum of the atomic masses of the atoms in a molecule.

Formula unit A group represented by a substance's chemical formula—that is, a group containing the kinds and numbers of atoms or ions listed in the chemical formula. It is a general term that can be used in reference to elements, molecular compounds, or ionic compounds.

Formula mass The weighted average of the masses of the naturally occurring formula units of the substance. It is the sum of the atomic masses of the atoms in a formula unit.

Empirical formula A chemical formula that includes positive integers that describe the simplest ratio of the atoms of each element in a compound.

Molecular formula The chemical formula that describes the actual numbers of atoms of each element in a molecule of a compound.

You can test yourself on the glossary terms at the textbook's Web site.

The goal of this chapter is to teach you to do the following.

Chapter
Objectives

1. Define all of the terms in the Chapter Glossary.

Section 6.1 Ionic Nomenclature

2. Convert between the names and chemical formulas for the monatomic ions.
3. Write or identify the roots of the names of the nonmetallic elements. (For example, the root for oxygen is ox-).
4. Convert between the names and chemical formulas for common polyatomic ions such as hydroxide, ammonium, acetate, sulfate, nitrate, phosphate, and carbonate. *Be sure to check with your instructor to determine which polyatomic ions you will be expected to know for your exams.*
5. Convert between the names and chemical formulas for the polyatomic anions that are derived from the additions of H^+ ions to anions with -2 or -3 charges. For example, H_2PO_4^- is dihydrogen phosphate.
6. Write the chemical formula corresponding to the common name bicarbonate.
7. Convert between the names and chemical formulas for ionic compounds.

Section 6.2 Binary Covalent Nomenclature

8. Convert between the names and chemical formulas for water, ammonia, methane, ethane, and propane.
9. Given a formula or name for a compound, identify whether it represents a binary covalent compound.
10. Write or identify prefixes for the numbers 1-10. (For example, mono- represents one, di- represents two, etc.)
11. Convert among the complete name, the common name, and the chemical formula for HF, HCl, HBr, HI, and H_2S .
12. Convert between the systematic names and chemical formulas for binary covalent compounds.

Section 6.3 Acids

13. Identify acids as substances that taste sour.
14. Describe what occurs when a strong, monoprotic acid, such as HCl, is added to water.
15. Identify the following acids as binary acids: $\text{HF}(aq)$, $\text{HCl}(aq)$, $\text{HBr}(aq)$, and $\text{HI}(aq)$.
16. Write or identify three different formulas that can be used to describe acetic acid, and explain why each is used.
17. Describe what occurs when a weak, monoprotic acid, such as acetic acid, is added to water.

18. Explain why weak acids produce fewer H_3O^+ ions in water than strong acids, even when the same numbers of acid molecules are added to equal volumes of water.
19. Identify the following as strong monoprotic acids: HCl and HNO_3 .
20. Identify sulfuric acid as a diprotic strong acid.
21. Describe what occurs when sulfuric acid is added to water.
22. Given a formula or name for any acid, identify it as a strong or weak acid.

Section 6.4 Acid Nomenclature

23. Convert between names and formulas for binary acids and oxyacids.

Section 6.5 Summary of Chemical Nomenclature

24. Given a name or chemical formula, tell whether it represents a binary ionic compound, an ionic compound with polyatomic ion(s), a binary covalent compound, a binary acid, or an oxyacid.
25. Convert between names and chemical formulas for binary ionic compounds, ionic compounds with polyatomic ion(s), binary covalent compounds, binary acids, and oxyacids.

Section 6.6 Molar Mass and Chemical Compounds

26. Given a formula for a molecular substance and a periodic table that includes atomic masses for the elements, calculate the substance's molecular mass.
27. Given enough information to calculate a molecular substance's molecular mass, write a conversion factor that converts between mass and moles of the substance.
28. Given enough information to calculate a molecular substance's molecular mass, convert between mass and moles of the substance.
29. Explain why the term molecule is better applied to molecular substances, such as water, than to ionic compounds, such as NaCl .
30. Given the name or chemical formula of a compound, identify whether it would be better to use the term *molecule* or the term *formula unit* to describe the group that contains the number of atoms or ions of each element equal to the subscript for the element in its chemical formula.
31. Given a formula for an ionic compound and a periodic table that includes atomic masses for the elements, calculate the compound's formula mass.
32. Given enough information to calculate an ionic compound's formula mass, write a conversion factor that converts between mass and moles of the compound.
33. Given enough information to calculate an ionic compound's formula mass, convert between mass and moles of the compound.

Section 6.7 Relationships Between Masses of Elements and Compounds

34. Given a formula for a compound, write conversion factors that convert between moles of atoms of each element in the compound and moles of compound.
35. Given the name or formula for an ionic compound, determine the number of moles of each ion in one mole of the compound.
36. Make conversions between the mass of a compound and the mass of an element in the compound.

Section 6.8 Determination of Empirical and Molecular Formulas

37. Given the masses of each element in a sample of a compound, calculate the compound's empirical formula.
38. Given the mass percentage of each element in a compound, calculate the compound's empirical formula.
39. Given an empirical formula for a molecular compound (or enough information to calculate the empirical formula) and given the molecular mass of the compound, determine its molecular formula.

1. Classify each of the following as either an ionic compound or a molecular compound.
- | | |
|--------------------|-----------------------------|
| a. MgCl_2 | d. Na_2SO_4 |
| b. PCl_3 | e. H_2SO_3 |
| c. KHSO_4 | |
2. When an atom of each of the following elements forms an ion, what ionic charge or charges would you expect it to have?
- | | |
|----------------|-----------------|
| a. calcium, Ca | d. lithium, Li |
| b. oxygen, O | e. aluminum, Al |
| c. bromine, Br | f. nitrogen, N |
3. Define the following terms.
- | | |
|---------------------|-------------------|
| a. monatomic anion | c. polyatomic ion |
| b. monatomic cation | |
4. Convert 37.625 g phosphorus, P, to moles.

Review Questions

Complete the following statements by writing one of these words or phrases in each blank.

acid	kinds
acidic	molecules
atoms	monatomic cations
binary	nearly one
diprotic	nonmetallic
double	numbers
forming	one hydrogen ion
formula	re-forming
formula unit	(root)ate
formula units	significantly less than one
H^+	simplest
$\text{H}_a\text{X}_b\text{O}_c$	single
halogens	sour
hydro-	specific type of compound
hydronium ions, H_3O^+	weak
-ic	whole-number

Key Ideas

5. To write the name that corresponds to a formula for a compound, you need to develop the ability to recognize the formula as representing a(n) _____.
6. The names of _____ always start with the name of the metal, sometimes followed by a Roman numeral to indicate the charge of the ion.
7. It is common for hydrogen atoms to be transferred from one ion or molecule to another ion or molecule. When this happens, the hydrogen atom is usually transferred without its electron, as _____.
8. Ionic compounds whose formula contains one symbol for a metal and one symbol for a nonmetal are called _____ ionic compounds.
9. You can recognize binary covalent compounds from their formulas, which contain symbols for only two _____ elements.
10. Any substance that has a(n) _____ taste is an acid.
11. According to the modern form of the Arrhenius theory, an acid is a substance that produces _____ when it is added to water.
12. On the basis of the Arrhenius definitions, a(n) _____ solution is a solution with a significant concentration of H_3O^+ .
13. The binary acids have the general formula of $\text{HX}(aq)$, where X is one of the first four _____.
14. Oxyacids (often called oxoacids) are molecular substances that have the general formula _____.
15. If each molecule of an acid can donate _____, the acid is called a monoprotic acid. A(n) _____ acid, such as sulfuric acid, H_2SO_4 , has two acidic hydrogen atoms.
16. Strong acids form _____ H_3O^+ ion in solution for each acid molecule dissolved in water, whereas weak acids yield _____ H_3O^+ ion in solution for each acid molecule dissolved in water.
17. A reaction in which the reactants are constantly _____ products and, at the same time, the products are _____ the reactants is called a reversible reaction. The chemical equations for reactions that are significantly reversible are written with _____ arrows.
18. A(n) _____ acid is a substance that is incompletely ionized in water because of the reversibility of its reaction with water that forms hydronium ion, H_3O^+ .
19. The chemical equations for completion reactions are written with _____ arrows to indicate that the reaction proceeds to form almost 100% products.
20. Binary acids are named by writing _____ followed by the root of the name of the halogen, then _____, and finally _____.
21. If enough H^+ ions are added to a(n) _____ polyatomic ion to completely neutralize its charge, the (root)ic acid is formed.
22. The molecular mass of the compound is the weighted average mass of the compound's naturally occurring _____.
23. In this text, the term _____ is used to describe ionic compounds in situations where molecule is used to describe molecular substances. It is the group represented by the substance's chemical formula, that is, a group containing the _____ and _____ of atoms or ions listed in the chemical formula.

24. Formula mass is the weighted average of the masses of the naturally occurring _____ of the substance.
25. We can convert between moles of element and moles of a compound containing that element by using the molar ratio derived from the _____ for the compound.
26. When the subscripts in a chemical formula represent the _____ ratio of the kinds of atoms in the compound, the formula is called an empirical formula.
27. A molecular formula describes the actual numbers of _____ in a molecule.
28. The subscripts in a molecular formula are always _____ multiples of the subscripts in the empirical formula.

Section 6.1 Ionic Nomenclature

29. Write the name for each of these monatomic ions.

- | | |
|---------------------|---------------------|
| a. Ca^{2+} | e. Ag^+ |
| b. Li^+ | f. Sc^{3+} |
| c. Cr^{2+} | g. P^{3-} |
| d. F^- | h. Pb^{2+} |

Chapter Problems

OBJECTIVE 2

30. Write the name for each of these monatomic ions.

- | | |
|---------------------|---------------------|
| a. Na^+ | e. Se^{2-} |
| b. Br^- | f. Zn^{2+} |
| c. Al^{3+} | g. Cr^{3+} |
| d. Mn^{2+} | |

OBJECTIVE 2

31. Write the formula for each of these monatomic ions.

- | | |
|------------------|-----------------------|
| a. magnesium ion | e. scandium ion |
| b. sodium ion | f. nitride ion |
| c. sulfide ion | g. manganese(III) ion |
| d. iron(III) ion | h. zinc ion |

OBJECTIVE 2

32. Write the formula for each of these monatomic ions.

- | | |
|-------------------|--------------------|
| a. strontium ion | f. oxide ion |
| b. aluminum ion | g. chloride ion |
| c. silver ion | h. copper(I) ion |
| d. nickel(II) ion | i. mercury(II) ion |
| e. potassium ion | |

OBJECTIVE 2

33. Write the name for each of these polyatomic ions.

- | | |
|---------------------------------------|---------------------|
| a. NH_4^+ | c. HSO_4^- |
| b. $\text{C}_2\text{H}_3\text{O}_2^-$ | |

OBJECTIVE 4

34. Write the name for each of these polyatomic ions.

- | | |
|-----------------------|---------------------|
| a. OH^- | c. HCO_3^- |
| b. CO_3^{2-} | |

OBJECTIVE 4

OBJECTIVE 4

35. Write the formula for each of these polyatomic ions.
- ammonium ion
 - bicarbonate ion
 - hydrogen sulfate ion

OBJECTIVE 7



36. Write the name for each of these chemical formulas.
- Na_2O (a dehydrating agent)
 - Ni_2O_3 (in storage batteries)
 - $\text{Pb}(\text{NO}_3)_2$ (in matches and explosives)
 - $\text{Ba}(\text{OH})_2$ (an analytical reagent)
 - KHCO_3 (in baking powder and fire-extinguishing agents)

OBJECTIVE 7

37. Write the name for each of these chemical formulas.
- CdI_2 (a nematocide—that is, it kills certain parasitic worms.)
 - Ca_3P_2 (in signal flares)
 - $\text{Au}(\text{OH})_3$ (used in gold plating)
 - FeCl_2 (in pharmaceutical preparations)
 - NH_4HSO_4 (in hair wave formulations)

OBJECTIVE 7

38. Write the chemical formula for each of the following names.
- potassium sulfide (a depilatory)
 - zinc phosphide (a rodenticide)
 - nickel(II) chloride (used in nickel electroplating)
 - magnesium dihydrogen phosphate (used in fireproofing wood)
 - lithium bicarbonate (in mineral waters)

OBJECTIVE 7

39. Write chemical formulas for each of the following names.
- barium chloride (used in manufacture of white leather)
 - cobalt(III) oxide (used in coloring enamels)
 - manganese(II) chloride (used in pharmaceutical preparations)
 - iron(III) acetate (a medicine)
 - chromium(III) phosphate (in paint pigments)
 - magnesium hydrogen phosphate (a laxative)

OBJECTIVE 7

40. The ionic compounds CuF_2 , NH_4Cl , CdO , and HgSO_4 are all used to make batteries. Write the name for each of these compounds.

OBJECTIVE 7

41. The ionic compounds MgF_2 , NH_4OH , $\text{Ba}(\text{NO}_3)_2$, Na_2HPO_4 , and Cu_2O are all used to make ceramics. Write the name for each of these compounds.

OBJECTIVE 7

42. The ionic compounds copper(II) chloride, lithium nitrate, and cadmium sulfide are all used to make fireworks. Write the chemical formulas for these compounds.

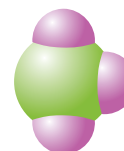
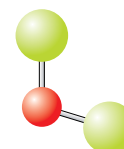
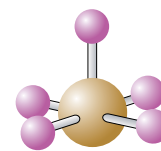
OBJECTIVE 7

43. The ionic compounds barium bromide, silver phosphate, and ammonium iodide are all used in photography. Write the chemical formulas for these compounds.

Section 6.2 Binary Covalent Nomenclature

44. What is wrong with using the name *nitrogen oxide* for NO ? Why can't you be sure of the formula that corresponds to the name *phosphorus chloride*?

45. The compound represented by the ball-and-stick model to the left is used in the processing of nuclear fuels. Although bromine atoms most commonly form one covalent bond, they can form five bonds, as in the molecule shown here, in which the central sphere represents a bromine atom. The other atoms are fluorine atoms. Write this compound's chemical formula and name. List the bromine atom first in the chemical formula.
46. The compound represented by the ball-and-stick model to the left is used to add chlorine atoms to other molecules. Write its chemical formula and name. The central ball represents an oxygen atom, and the other atoms are chlorine atoms. List the chlorine atom first in the chemical formula.
47. The compound represented by the space-filling model to the left is used to vulcanize rubber and harden softwoods. Write its chemical formula and name. The central ball represents a sulfur atom, and the other atoms are chlorineine atoms. List the sulfur atom first in the chemical formula.
48. The compound represented by the space-filling model to the left is used in processing nuclear fuels. The central sphere represents a chlorine atom, which in most cases would form one covalent bond but is sometimes able to form three bonds. The other atoms are fluorine atoms. Write this compound's chemical formula and name. List the chlorine atom first in the chemical formula.
49. Write the name for each of the following chemical formulas.
- I_2O_5 (an oxidizing agent)
 - BrF_3 (adds fluorine atoms to other compounds)
 - IBr (used in organic synthesis)
 - CH_4 (a primary component of natural gas)
 - HBr (used to make pharmaceuticals)
50. Write the name for each of the following chemical formulas.
- ClO_2 (a commercial bleaching agent)
 - C_2H_6 (in natural gas)
 - HI (when dissolved in water, used to make pharmaceuticals)
 - P_3N_5 (for doping semiconductors)
 - BrCl (an industrial disinfectant)
51. Write the chemical formula for each of the following names.
- propane (a fuel in heating torches)
 - chlorine monofluoride (a fluorinating agent)
 - tetraphosphorus heptasulfide (dangerous fire risk)
 - carbon tetrabromide (used to make organic compounds)
 - hydrogen fluoride (an additive to liquid rocket propellants)
52. Write the chemical formula for each of the following names.
- ammonia (a household cleaner when dissolved in water)
 - tetraphosphorus hexasulfide (used in organic chemical reactions)
 - iodine monochloride (used for organic synthesis)
 - hydrogen chloride (used to make hydrochloric acid)



OBJECTIVE 8

OBJECTIVE 11

OBJECTIVE 12

OBJECTIVE 8

OBJECTIVE 11

OBJECTIVE 12

OBJECTIVE 8,11,12



OBJECTIVE 8

OBJECTIVE 11

OBJECTIVE 12

Section 6.3 Acids

OBJECTIVE 14

53. Describe how the strong monoprotic acid nitric acid, HNO_3 (used in the reprocessing of spent nuclear fuels) acts when it is added to water, including a description of the nature of the particles in solution before and after the reaction with water. If there is a reversible reaction with water, describe the forward and the reverse reactions.

OBJECTIVE 17

54. Describe how the weak monoprotic acid hydrofluoric acid, HF (used in aluminum processing) acts when it is added to water, including a description of the nature of the particles in solution before and after the reaction with water. If there is a reversible reaction with water, describe the forward and the reverse reactions.

OBJECTIVE 21

55. Describe how the strong diprotic acid sulfuric acid, H_2SO_4 (used to make industrial explosives) acts when it is added to water, including a description of the nature of the particles in solution before and after the reaction with water. If there is a reversible reaction with water, describe the forward and the reverse reactions.

OBJECTIVE 16

56. Explain why acetic acid is described with three different formulas: $\text{HC}_2\text{H}_3\text{O}_2$, CH_3COOH , and $\text{CH}_3\text{CO}_2\text{H}$.

OBJECTIVE 18

57. Explain why weak acids produce fewer H_3O^+ ions in water than strong acids, even when the same number of acid molecules are added to equal volumes of water.

58. Classify each of the following acids as monoprotic, diprotic, or triprotic.

- $\text{HCl}(aq)$ (used in food processing)
- H_2SO_4 (used in petroleum refining)
- $\text{HC}_2\text{H}_3\text{O}_2$ (solvent in the production of polyesters)
- H_3PO_4 (catalyst for the production of ethanol)

OBJECTIVE 22

59. Identify each of the following as strong or weak acids.

- sulfurous acid (for bleaching straw)
- H_2SO_4 (used to make plastics)
- oxalic acid (in car radiator cleaners)

OBJECTIVE 22

60. Identify each of the following as strong or weak acids.

- $\text{HCl}(aq)$ (used to make dyes)
- nitrous acid (source of nitrogen monoxide, NO , used to bleach rayon)
- H_2CO_3 (formed when CO_2 dissolves in water)

OBJECTIVE 22

61. Identify each of the following as strong or weak acids.

- H_3PO_4 (added to animal feeds)
- hypophosphorous acid (in electroplating baths)
- $\text{HF}(aq)$ (used to process uranium)

62. Identify each of the following as strong or weak acids.

- benzoic acid (used to make a common food preservative, sodium benzoate)
- HNO_3 (used to make explosives)
- hydrocyanic acid (used to make rodenticides and pesticides)

63. For each of the following, write the chemical equation for its reaction with water.

- The monoprotic weak acid nitrous acid, HNO_2
- The monoprotic strong acid hydrobromic acid, HBr

64. For each of the following, write the chemical equation for its reaction with water.

- The monoprotic weak acid chlorous acid, HClO_2
- The monoprotic strong acid perchloric acid, HClO_4



OBJECTIVE 22

Sections 6.4 and 6.5 Acid Nomenclature and Summary of Chemical Nomenclature

65. Write the formulas and names of the acids that are derived from adding enough H^+ ions to the following ions to neutralize their charge.

- NO_3^-
- CO_3^{2-}
- PO_4^{3-}

66. Write the formulas and names of the acids that are derived from adding enough H^+ ions to the following ions to neutralize their charge.

- SO_4^{2-}
- $\text{C}_2\text{H}_3\text{O}_2^-$

67. Classify each of the following compounds as either (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the chemical formula that corresponds to each name.

- | | |
|------------------------------|--------------------------------|
| a. phosphoric acid | e. hydrochloric acid |
| b. ammonium bromide | f. magnesium nitride |
| c. diphosphorus tetrabromide | g. acetic acid |
| d. lithium hydrogen sulfate | h. lead(II) hydrogen phosphate |

68. Classify each of the following compounds as either (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the chemical formula that corresponds to each name.

- | | |
|-------------------------|------------------------------|
| a. potassium sulfide | e. copper(I) sulfate |
| b. sulfuric acid | f. hydrofluoric acid |
| c. ammonium nitrate | g. sodium hydrogen carbonate |
| d. iodine pentafluoride | |

69. Classify each of the following formulas as either (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the name that corresponds to each formula.

- | | |
|---------------------------------|---------------------------------|
| a. $\text{HBr}(aq)$ | e. H_2CO_3 |
| b. ClF_3 | f. $(\text{NH}_4)_2\text{SO}_4$ |
| c. CaBr_2 | g. KHSO_4 |
| d. $\text{Fe}_2(\text{SO}_4)_3$ | |

70. Classify each of the following formulas as either (1) a binary ionic compound, (2) an ionic compound with polyatomic ion(s), (3) a binary covalent compound, (4) a binary acid, or (5) an oxyacid. Write the name that corresponds to each formula.

- | | |
|----------------------------------|--------------------------|
| a. HNO_3 | e. $\text{HI}(aq)$ |
| b. $\text{Ca}(\text{OH})_2$ | f. Li_2O |
| c. $(\text{NH}_4)_2\text{HPO}_4$ | g. Br_2O |
| d. Ni_3P_2 | |

OBJECTIVE 23

OBJECTIVE 24

OBJECTIVE 25

OBJECTIVE 23

OBJECTIVE 24

OBJECTIVE 25

OBJECTIVE 23

OBJECTIVE 24

OBJECTIVE 25

OBJECTIVE 23

OBJECTIVE 24

OBJECTIVE 25

Section 6.6 Molar Masses and Chemical Compounds

OBJECTIVE 26

71. For each of the molecular substances (a) H_3PO_2 and (b) $\text{C}_6\text{H}_5\text{NH}_2$, calculate its molecular mass and write a conversion factor that converts between mass in grams and moles of the substance.

OBJECTIVE 27

OBJECTIVE 26

72. For each of the molecular substances (a) CF_3CHCl_2 and (b) SO_2Cl_2 , calculate its molecular mass and write a conversion factor that converts between mass in grams and moles of the substance.

OBJECTIVE 27

OBJECTIVE 28

73. Each dose of a nighttime cold medicine contains 1000 mg of the analgesic acetaminophen. Acetaminophen, or N-acetyl-p-aminophenol, has the general formula $\text{C}_8\text{H}_9\text{NO}$.

- How many moles of acetaminophen are in each dose?
- What is the mass in grams of 15.0 moles of acetaminophen?

OBJECTIVE 28

74. A throat lozenge contains 5.0 mg of menthol, which has the formula $\text{C}_{10}\text{H}_{20}\text{O}$.

- How many moles of menthol are in 5.0 mg of menthol?
- What is the mass in grams of 1.56 moles of menthol?

OBJECTIVE 29

75. A group of atoms that contains one atom of nitrogen and three atoms of hydrogen is called an ammonia *molecule*. A group of ions that contains one potassium ion and one fluoride ion is called a potassium fluoride *formula unit* instead of a *molecule*. Why?

OBJECTIVE 30

76. For each of the following examples, decide whether it would be better to use the term *molecule* or *formula unit*.

- Cl_2O
- Na_2O
- $(\text{NH}_4)_2\text{SO}_4$
- $\text{HC}_2\text{H}_3\text{O}_2$

OBJECTIVE 30

77. For each of the following examples, decide whether it would be better to use the term *molecule* or *formula unit*.

- K_2SO_3
- H_2SO_3
- CCl_4
- NH_4Cl

OBJECTIVE 31

78. For each of the ionic substances (a) BiBr_3 and (b) $\text{Al}_2(\text{SO}_4)_3$, calculate its formula mass and write a conversion factor that converts between mass in grams and moles of the substance.

OBJECTIVE 32

OBJECTIVE 31

79. For each of the following ionic substances (a) Co_2O_3 and (b) $\text{Fe}_2(\text{C}_2\text{O}_4)_3$, calculate its formula mass and write a conversion factor that converts between mass in grams and moles of the substance.

OBJECTIVE 32

OBJECTIVE 33

80. A common antacid tablet contains 500 mg of calcium carbonate, CaCO_3 .

- How many moles of CaCO_3 does each tablet contain?
- What is the mass in kilograms of 100.0 moles of calcium carbonate?

OBJECTIVE 33

81. An antacid contains 200 mg of aluminum hydroxide and 200 mg of magnesium hydroxide per capsule.

- How many moles of $\text{Al}(\text{OH})_3$ does each capsule contain?
- What is the mass in milligrams of 0.0457 mole of magnesium hydroxide?

OBJECTIVE 33

82. Rubies and other minerals in the durable corundum family are primarily composed of aluminum oxide, Al_2O_3 , with trace impurities that lead to their different colors. For example, the red color in rubies comes from a small amount of chromium replacing some of the aluminum. If a 0.78-carat ruby were pure aluminum oxide, how many moles of Al_2O_3 would be in the stone? (There are exactly 5 carats per gram.)

83. Many famous “rubies” are in fact spinels, which look like rubies but are far less valuable. Spinel consists primarily of MgAl_2O_4 , whereas rubies are primarily Al_2O_3 . If the Timur Ruby, a 361-carat spinel, were pure MgAl_2O_4 , how many moles of MgAl_2O_4 would it contain? (There are exactly 5 carats per gram.)

OBJECTIVE 33



Section 6.7 Relationship Between Masses of Elements and Compounds

84. Write a conversion factor that converts between moles of nitrogen in nitrogen pentoxide, N_2O_5 , and moles of N_2O_5 .
85. Write a conversion factor that converts between moles of oxygen in phosphoric acid, H_3PO_4 , and moles of H_3PO_4 .
86. The green granules on older asphalt roofing are chromium(III) oxide. Write a conversion factor that converts between moles of chromium ions in chromium(III) oxide, Cr_2O_3 , and moles of Cr_2O_3 .
87. Calcium phosphide is used to make fireworks. Write a conversion factor that converts between moles of calcium ions in calcium phosphide, Ca_3P_2 , and moles of Ca_3P_2 .
88. Ammonium oxalate is used for stain and rust removal. How many moles of ammonium ions are in 1 mole of ammonium oxalate, $(\text{NH}_4)_2\text{C}_2\text{O}_4$?
89. Magnesium phosphate is used as a dental polishing agent. How many moles of ions (cations and anions together) are in 1 mole of magnesium phosphate, $\text{Mg}_3(\text{PO}_4)_2$?
90. A nutritional supplement contains 0.405 g of CaCO_3 . The recommended daily value of calcium is 1.000 g Ca.
- Write a conversion factor that relates moles of calcium to moles of calcium carbonate.
 - Calculate the mass in grams of calcium in 0.405 g of CaCO_3 .
 - What percentage of the daily value of calcium comes from this tablet?
91. A multivitamin tablet contains 0.479 g of CaHPO_4 as a source of phosphorus. The recommended daily value of phosphorus is 1.000 g of P.
- Write a conversion factor that relates moles of phosphorus to moles of calcium hydrogen phosphate.
 - Calculate the mass in grams of phosphorus in 0.479 g of CaHPO_4 .
 - What percentage of the daily value of phosphorus comes from this tablet?
92. A multivitamin tablet contains 10 μg of vanadium in the form of sodium metavanadate, NaVO_3 . How many micrograms of NaVO_3 does each tablet contain?
93. A multivitamin tablet contains 5 μg of nickel in the form of nickel(II) sulfate. How many micrograms of NiSO_4 does each tablet contain?
94. There are several natural sources of the element titanium. One is the ore called rutile, which contains oxides of iron and titanium, FeO and TiO_2 . Titanium metal can be made by first converting the TiO_2 in rutile to TiCl_4 by heating the ore to high temperature in the presence of carbon and chlorine. The titanium in TiCl_4 is then reduced from its +4 oxidation state to its zero oxidation state by reaction with a good reducing agent such as magnesium or sodium. What is the mass of titanium in kilograms in 0.401 Mg of TiCl_4 ?

OBJECTIVE 34

OBJECTIVE 34

OBJECTIVE 35

OBJECTIVE 35

OBJECTIVE 35

OBJECTIVE 35

OBJECTIVE 34

OBJECTIVE 36

OBJECTIVE 34

OBJECTIVE 36

OBJECTIVE 36

OBJECTIVE 36

OBJECTIVE 36

OBJECTIVE 36

95. Manganese metal is produced from the manganese(III) oxide, Mn_2O_3 , which is found in manganite, a manganese ore. The manganese is reduced from its +3 oxidation state in Mn_2O_3 to the zero oxidation state of the uncharged metal by reacting the Mn_2O_3 with a reducing agent such as aluminum or carbon. How many pounds of manganese are in 1.261 tons of Mn_2O_3 ? (1 ton = 2000 pounds)

Section 6.8 Determination of Empirical and Molecular Formulas

OBJECTIVE 37

96. Explain the difference between molecular formulas and empirical formulas. Give an example of a substance whose empirical formula is different from its molecular formula. Give an example of a substance whose empirical formula and molecular formula are the same.

OBJECTIVE 37

97. An extremely explosive ionic compound is made from the reaction of silver compounds with ammonia. A sample of this compound is found to contain 17.261 g of silver and 0.743 g of nitrogen. What is the empirical formula for this compound? What is its chemical name?



98. A sample of an ionic compound that is often used as a dough conditioner is analyzed and found to contain 7.591 g of potassium, 15.514 g of bromine, and 9.319 g of oxygen. What is the empirical formula for this compound? What is its chemical name?

OBJECTIVE 37

99. A sample of a compound used to polish dentures and as a nutrient and dietary supplement is analyzed and found to contain 9.2402 g of calcium, 7.2183 g of phosphorus, and 13.0512 g of oxygen. What is the empirical formula for this compound?

OBJECTIVE 37

100. A sample of an ionic compound that is used in the semiconductor industry is analyzed and found to contain 53.625 g of indium and 89.375 g of tellurium. What is the empirical formula for this compound?

OBJECTIVE 38

101. An ionic compound that is 38.791% nickel, 33.011% arsenic, and 28.198% oxygen is employed as a catalyst for hardening fats used to make soap. What is the empirical formula for this compound?

OBJECTIVE 38

102. An ionic compound sometimes called TKPP is used as a soap and detergent builder. It is 47.343% potassium, 18.753% phosphorus, and 33.904% oxygen. What is the empirical formula for this compound?

OBJECTIVE 38

103. An ionic compound that contains 10.279% calcium, 65.099% iodine, and 24.622% oxygen is used in deodorants and in mouthwashes. What is the empirical formula for this compound? What do you think its chemical name is? (Consider the possibility that this compound contains more than one polyatomic ion.)

OBJECTIVE 38

104. An ionic compound that is 62.56% lead, 8.46% nitrogen, and 28.98% oxygen is used as a mordant in the dyeing industry. A mordant helps to bind a dye to the fabric. What is the empirical formula for this compound? What do you think its name is? (Consider the possibility that this compound contains more than one polyatomic ion.)



105. In 1989 a controversy arose concerning the chemical daminozide, or Alar[®], which was sprayed on apple trees to yield redder, firmer, and more shapely apples. Concerns about Alar's safety stemmed from the suspicion that one of its breakdown products, unsymmetrical dimethylhydrazine (UDMH), was carcinogenic. Alar is no longer sold for food uses. UDMH has the empirical

- formula of CNH_4 and has a molecular mass of 60.099. What is the molecular formula for UDMH?
106. It would be advisable for the smokers of the world to consider that nicotine was once used as an insecticide but is no longer used for that purpose because of safety concerns. Nicotine has an empirical formula of $\text{C}_5\text{H}_7\text{N}$ and a molecular mass of 162.23. What is the molecular formula for nicotine? OBJECTIVE 39
107. Lindane is one of the chlorinated pesticides the use of which is now restricted in the United States. It is 24.78% carbon, 2.08% hydrogen, and 73.14% chlorine and has a molecular mass of 290.830. What is lindane's molecular formula? OBJECTIVE 38
OBJECTIVE 39
108. Hydralazine is a drug used to treat heart disease. It is 59.99% carbon, 5.03% hydrogen, and 34.98% nitrogen and has a molecular mass of 160.178. What is the molecular formula for hydralazine? OBJECTIVE 38
OBJECTIVE 39
109. Melamine is a compound used to make the melamine-formaldehyde resins in very hard surface materials such as Formica[®]. It is 28.57% carbon, 4.80% hydrogen, and 66.63% nitrogen and has a molecular mass of 126.121. What is melamine's molecular formula? OBJECTIVE 38
OBJECTIVE 39
110. About 40 different substances called organophosphorus compounds are registered in the United States as insecticides. They are considered less damaging to the environment than some other insecticides because they breakdown relatively rapidly in the environment. The first of these organophosphorus insecticides to be produced was tetraethyl pyrophosphate, TEPP, which is 33.11% carbon, 6.95% hydrogen, 38.59% oxygen, and 21.35% phosphorus. It has a molecular mass of 290.190. What is the molecular formula for TEPP? OBJECTIVE 38
OBJECTIVE 39

Additional Problems

111. Your boss at the hardware store points you to a bin of screws and asks you to find out the approximate number of screws it contains. You weigh the screws and find that their total mass is 68 pounds. You take out 100 screws and weigh them individually, and you find that 7 screws weigh 2.65 g, 4 screws weigh 2.75 g, and 89 screws weigh 2.90 g. Calculate the weighted average mass of each screw. How many screws are in the bin? How many gross of screws are in the bin?
112. Atomic masses are derived from calculations using experimental data. As the experiments that provide this data get more precise, the data get more accurate, and the atomic masses values reported on the periodic table are revised. One source of data from 1964 reports that the element potassium is 93.10% potassium-39, which has atoms with a mass of 38.963714 u (atomic mass units), 0.0118% potassium-40, which has atoms with a mass of 39.964008 u, and 6.88% potassium-41, which has atoms with a mass of 40.961835 u. Using this data, calculate the weighted average mass of potassium atoms, in atomic mass units. Report your answer to the fourth decimal position. The weighted average mass of potassium atoms is potassium's atomic mass. How does your calculated value compare to potassium's reported atomic mass on the periodic table in this text?





- 113.** As a member of the corundum family of minerals, sapphire (the September birthstone) consists primarily of aluminum oxide, Al_2O_3 . Small amounts of iron and titanium give it its rich dark blue color. Gem cutter Norman Maness carved a giant sapphire into the likeness of Abraham Lincoln. If this 2302-carat sapphire were pure aluminum oxide, how many moles of Al_2O_3 would it contain? (There are exactly 5 carats per gram.)



114. Emeralds are members of the beryl family, which are silicates of beryllium and aluminum with a general formula of $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$. The emerald's green color comes from small amounts of chromium in the crystal. The Viennese treasury has a cut emerald that weighs 2205 carats. If this stone were pure $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$, how many moles of $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$ would it contain? (There are exactly 5 carats per gram.)

- 115.** Aquamarine (the March birthstone) is a light blue member of the beryl family, which is made up of natural silicates of beryllium and aluminum that have the general formula $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$. Aquamarine's bluish color is caused by trace amounts of iron(II) ions. A 43-pound aquamarine mined in Brazil in 1910 remains the largest gem-quality crystal ever found. If this stone were pure $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$, how many moles of beryllium would it contain?

116. In 1985 benitoite became the California "state gemstone." Found only in a tiny mine near Coalinga, California, it is a silicate of barium and titanium with trace impurities that cause a range of hues from colorless to blue to pink. Its general formula is $\text{BaTi}(\text{SiO}_3)_3$. If a 15-carat stone were pure $\text{BaTi}(\text{SiO}_3)_3$, how many moles of silicon would it contain?

- 117.** November's birthstone is citrine, a yellow member of the quartz family. It is primarily silicon dioxide, but small amounts of iron(III) ions give it its yellow color. A high-quality citrine containing about 0.040 moles of SiO_2 costs around \$225. If this stone were pure SiO_2 , how many carats would it weigh? (There are exactly 5 carats per gram.)



118. The gemstone tanzanite was first discovered in Tanzania in 1967. Like other gemstones, it contains impurities that give it distinct characteristics, but it is primarily $\text{Ca}_2\text{Al}_3\text{Si}_3\text{O}_{12}(\text{OH})$. The largest tanzanite stone ever found contains about 0.0555 mole of $\text{Ca}_2\text{Al}_3\text{Si}_3\text{O}_{12}(\text{OH})$. What is the mass of this stone in kilograms?

- 119.** A common throat lozenge contains 29 mg of phenol, $\text{C}_6\text{H}_5\text{OH}$.
- How many moles of $\text{C}_6\text{H}_5\text{OH}$ are there in 5.0 mg of phenol?
 - What is the mass in kilograms of 0.9265 mole of phenol?

120. Some forms of hematite, a mineral composed of iron(III) oxide, can be used to make jewelry. Because of its iron content, hematite jewelry has a unique problem among stone jewelry. It shows signs of rusting. How many moles of iron are there in a necklace that contains 78.435 g of Fe_2O_3 ?

- 121.** Beryl, $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$, is a natural source of beryllium, a known carcinogen. What is the mass in kilograms of beryllium in 1.006 Mg of $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$?

122. The element antimony is used to harden lead for use in lead-acid storage batteries. One of the principal antimony ores is stibnite, which contains antimony in the form of Sb_2S_3 . Antimony is obtained through the reduction that occurs (from the +3 oxidation state to the zero oxidation state of pure antimony) when Sb_2S_3 reacts with the iron in iron scrap. What is the mass of antimony in 14.78 lb of Sb_2S_3 ?
123. Cermets (for *ceramic plus metal*) are synthetic substances with both ceramic and metallic components. They combine the strength and toughness of metal with the resistance to heat and oxidation that ceramics offer. One cermet containing molybdenum and silicon was used to coat molybdenum engine parts on space vehicles. A sample of this compound is analyzed and found to contain 14.212 g of molybdenum and 8.321 g of silicon. What is the empirical formula for this compound?
124. Blue vitriol is a common name for an ionic compound that has many purposes in industry, including the production of germicides, pigments, pharmaceuticals, and wood preservatives. A sample contains 20.238 g of copper, 10.213 g of sulfur, and 20.383 g of oxygen. What is its empirical formula? What is its name?
125. A compound that is sometimes called sorrel salt can be used to remove ink stains or to clean wood. It is 30.52% potassium, 0.787% hydrogen, 18.75% carbon, and 49.95% oxygen. What is the empirical formula for this compound?
126. The ionic compound sometimes called uranium yellow is used to produce colored glazes for ceramics. It is 7.252% sodium, 75.084% uranium, and 17.664% oxygen. What is the empirical formula for this compound?
127. An ionic compound that is 24.186% sodium, 33.734% sulfur, and 42.080% oxygen is used as a food preservative. What is its empirical formula?
128. A defoliant is an herbicide that removes leaves from trees and growing plants. One ionic compound used for this purpose is 12.711% magnesium, 37.083% chlorine, and 50.206% oxygen. What is the empirical formula for this compound? What do you think its chemical name is? (Consider the possibility that this compound contains more than one polyatomic ion.)
129. An ionic compound that is 22.071% manganese, 1.620% hydrogen, 24.887% phosphorus, and 51.422% oxygen is used as a food additive and dietary supplement. What is the empirical formula for this compound? What do you think its chemical name is? (Consider the possibility that this compound contains more than one polyatomic ion.)
130. Agent Orange, which was used as a defoliant in the Vietnam War, contained a mixture of two herbicides called 2,4,5-T and 2,4-D. (Agent Orange got its name from the orange barrels in which it was stored.) Some of the controversy that surrounds the use of Agent Orange is related to the discovery in 2,4,5-T of a trace impurity called TCDD. Although recent studies suggest that it is much more harmful to animals than to humans, TCDD has been called the most toxic small molecule known, and all uses of 2,4,5-T were banned in 1985. TCDD is 44.77% carbon, 1.25% hydrogen, 9.94% oxygen, and 44.04% chlorine and has a molecular mass of 321.97. What is the molecular formula for TCDD?

- 131.** Thalidomide was used as a tranquilizer and flu medicine for pregnant women in Europe until it was found to cause birth defects. (The horrible effects of this drug played a significant role in the passage of the Kefauver-Harris Amendment to the Food and Drug Act, requiring that drugs be proved safe before they are put on the market.) Thalidomide is 60.47% carbon, 3.90% hydrogen, 24.78% oxygen, and 10.85% nitrogen and has a molecular mass of 258.23. What is the molecular formula for thalidomide?
- 132.** Nabam is a fungicide used on potato plants. It is 17.94% sodium, 18.74% carbon, 2.36% hydrogen, 10.93% nitrogen, and 50.03% sulfur and has a formula mass of 256.35. Nabam is an ionic compound with a formula that is not an empirical formula. What is the formula for nabam?



Challenge Problems

- 133.** Calamine is a naturally occurring zinc silicate that contains the equivalent of 67.5% zinc oxide, ZnO . (The term *calamine* also refers to a substance used to make calamine lotion.) What is the mass, in kilograms, of zinc in 1.347×10^4 kg of natural calamine that is 67.5% ZnO ?
- 134.** Zirconium metal, which is used to coat nuclear fuel rods, can be made from the zirconium(IV) oxide, ZrO_2 , in the zirconium ore called baddeleyite (or zirconia). What maximum mass in kilograms of zirconium metal can be extracted from 1.2×10^3 kg of baddeleyite that is 53% ZrO_2 ?
- 135.** Flue dust from the smelting of copper and lead contains As_2O_3 . (Smelting is the heating of a metal ore until it melts, so that its metallic components can be separated.) When this flue dust is collected, it contains 90% to 95% As_2O_3 . The arsenic in As_2O_3 can be reduced to the element arsenic by reaction with charcoal. What is the maximum mass, in kilograms, of arsenic that can be formed from 67.3 kg of flue dust that is 93% As_2O_3 ?
- 136.** Thortveitite is a natural ore that contains from 37% to 42% scandium oxide, Sc_2O_3 . Scandium metal is made by first reacting the Sc_2O_3 with ammonium hydrogen fluoride, NH_4HF_2 , to form scandium fluoride, ScF_3 . The scandium in ScF_3 is reduced to metallic scandium in a reaction with calcium. What is the maximum mass, in kilograms, of scandium metal that can be made from 1230.2 kilograms of thortveitite that is 39% Sc_2O_3 ?
- 137.** Magnesium metal, which is used to make die-cast auto parts, missiles, and space vehicles, is obtained by the electrolysis of magnesium chloride. Magnesium hydroxide forms magnesium chloride when it reacts with hydrochloric acid. There are two common sources of magnesium hydroxide.
- Magnesium ions can be precipitated from seawater as magnesium hydroxide, $\text{Mg}(\text{OH})_2$. Each kiloliter of seawater yields about 3.0 kg of the compound. How many metric tons of magnesium metal can be made from the magnesium hydroxide derived from 1.0×10^5 kL of seawater?
 - Brucite is a natural form of magnesium hydroxide. A typical crude ore containing brucite is 29% $\text{Mg}(\text{OH})_2$. What minimum mass, in metric tons, of this crude ore is necessary to make 34.78 metric tons of magnesium metal?

138. Spodumene is a lithium aluminum silicate containing the equivalent of 6.5% to 7.5% lithium oxide, Li_2O . Crude ore mined in North Carolina contains 15% to 20% spodumene. What maximum mass, in kilograms, of lithium could be formed from 2.538 megagrams of spodumene containing the equivalent of 7.0% Li_2O ?
139. The element fluorine can be obtained by the electrolysis of combinations of hydrofluoric acid and potassium fluoride. These compounds can be made from the calcium fluoride, CaF_2 , found in nature as the mineral fluorite. Fluorite's commercial name is fluorspar. Crude ores containing fluorite have 15% to 90% CaF_2 . What minimum mass, in metric tons, of crude ore is necessary to make 2.4 metric tons of fluorine if the ore is 72% CaF_2 ?
140. Chromium metal is used in metal alloys and as a surface plating on other metals to minimize corrosion. It can be obtained by reducing the chromium(III) in chromium(III) oxide, Cr_2O_3 , to the uncharged metal with finely divided aluminum. The Cr_2O_3 is found in an ore called chromite. What is the maximum mass, in kilograms, of chromium that can be made from 143.0 metric tons of Cuban chromite ore that is 38% Cr_2O_3 ?
141. What mass of baking powder that is 36% NaHCO_3 contains 1.0 mole of sodium hydrogen carbonate?
142. Roscoelite is a vanadium-containing form of mica used to make vanadium metal. Although the fraction of vanadium in the ore is variable, roscelite can be described as $\text{K}_2\text{V}_4\text{Al}_2\text{Si}_6\text{O}_{20}(\text{OH})_4$. Another way to describe the vanadium content of this mineral is to say that it has the equivalent of up to 28% V_2O_3 .
- What is the mass, in grams, of vanadium in 123.64 g of roscelite?
 - What is the mass, in kilograms, of vanadium in 6.71 metric tons of roscelite that contains the equivalent of 28% V_2O_3 ?
143. Hafnium metal is used to make control rods in water-cooled nuclear reactors and to make filaments in light bulbs. The hafnium is found with zirconium in zircon sand, which is about 1% hafnium(IV) oxide, HfO_2 . What minimum mass, in metric tons, of zircon sand is necessary to make 120.5 kg of hafnium metal if the sand is 1.3% HfO_2 ?



Discussion Topic

144. It has been suggested that there is really only one type of chemical bond—that ionic and covalent bonds are not really fundamentally different. What arguments can be made for and against this position?