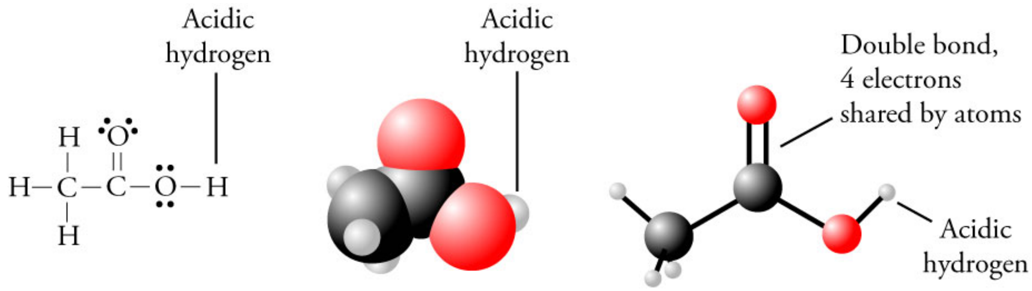
Chapter 6
More on Chemical Compounds



Section Goals and Introductions

As always, the Review Skills section for this chapter is important. A quick review of atomic mass and moles in Section 3.6, the information on ionic and molecular compounds in Section 5.2, and monatomic ion charges in Section 5.3 will be useful.

Section 6.1 Ionic Nomenclature

Goals

- *To show how to convert between chemical names and formulas for ionic compounds.*

This section begins the process of describing how to convert between names and formulas for compounds. How important this is depends on whether or not you are going to take more chemistry classes. For example, if you are going on to take general college chemistry, it's very important that you master this skill. It's much less important if the course for which you are using this text is the last chemistry course you plan to take. Be sure to ask your instructor how much weight will be given to this topic on your exams. The task of converting between names and formulas will be part of larger tasks found throughout your study of chemistry. Our Web site has tutorials that provide practice converting between names and formulas for monatomic ions.

Internet: Cation Nomenclature

Internet: Anion Nomenclature

Polyatomic ions (charged collections of atoms held together by covalent bonds) are also described. Your instructor may want to expand on the list of polyatomic ions that you are expected to know. The text assumes that you can convert between the names and symbols for those that are found in Table 6.3. The following section on our Web site gives you a more complete description of polyatomic ions.

Internet: Oxyanions

Our Web site has a tutorial that provides practice converting between names and formulas for ionic compounds:

Internet: Ionic Nomenclature

Section 6.2 Naming Binary Covalent Compounds

Goal: To show how to convert between names and formulas for binary covalent compounds.

There is a tutorial on our Web site that provides practice converting between names and formulas for binary covalent compounds:

Internet: Binary Covalent Nomenclature

Section 6.3 Acids

Goals

- *To describe acids*
- *To make the distinction between strong and weak acids.*
- *To show the changes that take place on the particle level when acids dissolve in water.*
- *To show how you can recognize strong and weak acids.*

This section introduces one way to define acids, called the Arrhenius definition. The most important skills to develop in this section are (1) to be able to recognize acids from names or formulas and (2) to be able to describe the changes that take place at the particle level when strong and weak acids dissolve in water. Be sure to give special attention to Figures 6.2, 6.6, and 6.7. Visit our Web site to view an animation that illustrates the differences between strong and weak acids:

Internet: Acid Animation

Section 6.4 Acid Nomenclature

- *Goal: To describe how to convert between names and chemical formulas for acids.*

This section adds acids to the list of compounds for which you should be able to convert between names and formulas.

Section 6.5 Summary of Chemical Nomenclature

- *Goal: To review the process for converting between names and formulas for binary covalent compounds, binary ionic compounds, ionic compounds with polyatomic ions, binary acids, and oxyacids.*

Although chemical nomenclature may not be your favorite topic, it is an important one. The ability to convert among names and formulas for chemical compounds is crucial to communication between chemists and chemistry students. Table 6.13 provides your most concise summary of the guidelines. Our Web site provides tutorials that allow you to practice identifying types of substances and converting between names and formulas for chemical compounds:

Internet: Types of Substances
Internet: Chemical Nomenclature

Section 6.6 Molar Mass and Chemical Compounds

Goals:

- *To introduce the chapter by describing a typical problem that you will be able to work after studying the chapter.*
- *To introduce molecular mass and formula mass and show how they can be used to convert between the mass of a sample of a compound and the number of molecules or formula units that the sample contains.*

This section shows how to calculate the number of molecules (expressed in moles) in a sample of a molecular compound from the mass of that sample and how to calculate the mass in a sample of a molecular compound from the moles of molecules it contains. The section also explains why ionic compounds do not contain molecules and how the term formula unit can be used to describe the units of ionic compounds that are like molecules of molecular compounds. Then you will see how to calculate the number of formula units in a sample of an ionic compound (expressed in moles) from the mass of that sample and how to calculate the mass of an ionic compound and the moles of formula units it contains. These calculations are very commonly done by chemists and chemistry students, so be sure you can do them quickly and correctly.

Section 6.7 Relationships Between Masses of Elements and Compounds

Goal: To show how you convert between mass of an element and mass of a compound that contains the element.

This section shows how you can use the skills you learned in Sections 3.6 and 6.6 and some information derived from chemical formulas for compounds to convert between mass of an element and mass of a compound that contains the element.

The section on our Web site called Percentage of an Element in a Compound describes calculations that are related to this section.

Internet: Percentage of an Element in a Compound

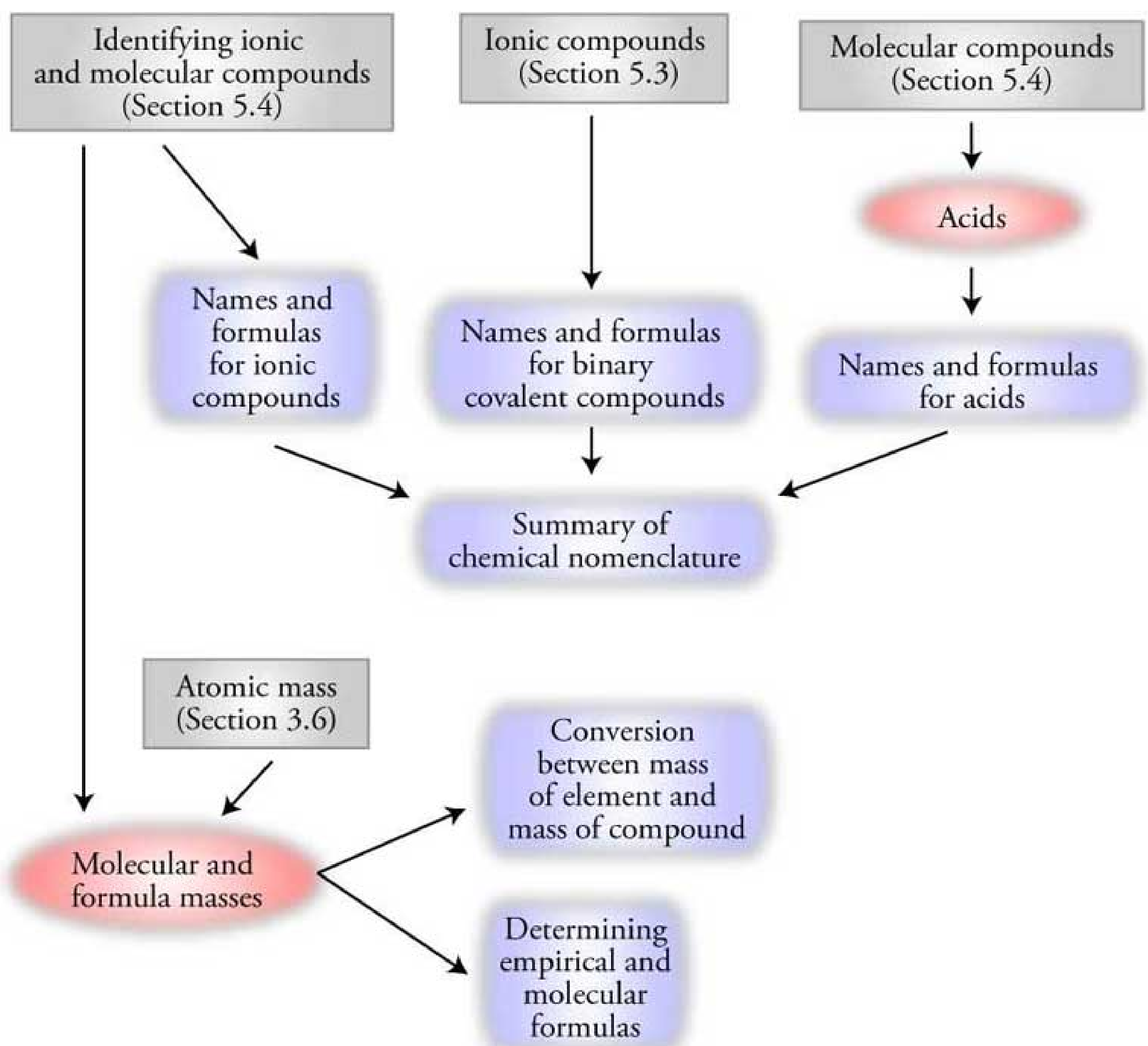
Section 6.8 Determination of Empirical and Molecular Formulas

Goal: To describe what empirical and molecular formulas are and how they can be determined.

All compounds can be described with empirical formulas, and molecular compounds can also be described with molecular formulas. This section describes the information given by each type of formula and shows ways to determine them. A section on our Web site describes an experimental technique used to determine empirical formulas.

Internet: Combustion Analysis

Chapter 6 Map



Chapter Checklist

- ☐ Read the Review Skills section. If there is any skill mentioned that you have not yet mastered, review the material on that topic before reading this chapter.
- ☐ Read the chapter quickly before the lecture that describes it.
- ☐ Attend class meetings, take notes, and participate in class discussions.
- ☐ Work the Chapter Exercises, perhaps using the Chapter Examples as guides.
- ☐ Study the Chapter Glossary and test yourself on our Web site:

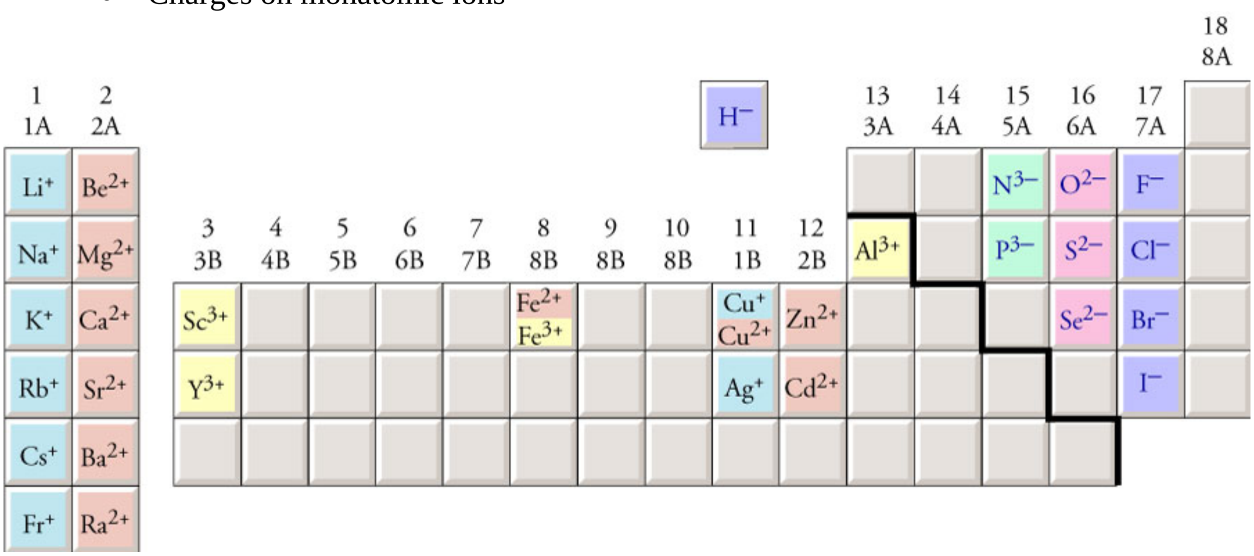
  Internet: Glossary Quiz

- ☐ Reread *Sample Study Sheet 6.1: Converting Between Mass of element and Mass of Compound Containing the Element, Sample Study Sheet 6.2: Calculating Empirical Formulas*, and *Sample Study Sheet 6.3: Calculating Molecular Formulas* and decide whether you will use them or some variation on them to complete the task they describe.
- ☐ Study all of the Chapter Objectives. You might want to write a description of how you will meet each objective. (Although it is best to master all of the objectives, the following objectives are especially important because they pertain to skills that you will need while studying other chapters of this text: 7, 12, 22, 23, 25, 28, 32, and 36.)
- ☐ Memorize the following. Be sure to check with your instructor to determine how much you are expected to know of the following.

  - Roots of nonmetallic elements

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

  - Charges on monatomic ions



- Names and formulas for polyatomic ions

Ion	Name	Ion	Name	Ion	Name
NH_4^+	ammonium	PO_4^{3-}	phosphate	SO_4^{2-}	sulfate
OH^-	hydroxide	NO_3^-	nitrate	$C_2H_3O_2^-$	acetate
CO_3^{2-}	carbonate				

- Names and formulas of some binary covalent compounds.

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

- Prefixes

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)-

- Guidelines for writing names and formulas for compounds

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) (root of nonmetal)ide	sodium chloride or iron(III) chloride
Ionic with polyatomic ion(s)	M_aX_b or $(NH_4)_aX_b$ X = recognized 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) (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

Notes: M = symbol of metal
A and B = symbols of nonmetals
X = some element other than H or O
a, b, & c indicate subscripts

- ☐ To get a review of the most important topics in the chapter, fill in the blanks in the Key Ideas section.
- ☐ Work all of the selected problems at the end of the chapter, and check your answers with the solutions provided in this chapter of the study guide.
- ☐ Ask for help if you need it.

Web Resources

Internet: Cation Nomenclature
Internet: Anion Nomenclature
Internet: Oxyanions
Internet: Ionic Nomenclature
Internet: Binary Covalent Nomenclature
Internet: Acid Animation
Internet: Acid Nomenclature
Internet: Types of Substances
Internet: Chemical Nomenclature
Internet: Percentage Element in Compound
Internet: Combustion Analysis
Internet: Glossary Quiz

Exercises Key

Exercise 6.1 - Naming Monatomic Ions: Write names that correspond to the following formulas for monatomic ions: *(Obj 2)*

a. Mg^{2+} **magnesium ion**
b. F^{-} **fluoride ion**
c. Sn^{2+} **tin(II) ion**

Exercise 6.2 - Formulas for Monatomic Ions: Write formulas that correspond to the following names for monatomic ions: *(Obj 2)*

a. bromide ion **Br^{-}**
b. aluminum ion **Al^{3+}**
c. gold(I) ion **Au^{+}**

Exercise 6.3 - Naming Ionic Compounds: Write the names that correspond to the following formulas: *(Obj 7)*

a. LiCl **lithium chloride**
b. $Cr_2(SO_4)_3$ **chromium(III) sulfate**
c. NH_4HCO_3 **ammonium hydrogen carbonate**

Exercise 6.4 - Formulas for Ionic Compounds: Write the formulas that correspond to the following names: *(Obj 7)*

a. aluminum oxide **Al_2O_3**
b. cobalt(III) fluoride **CoF_3**
c. iron(II) sulfate **$FeSO_4$**
d. ammonium hydrogen phosphate **$(NH_4)_2HPO_4$**
e. potassium bicarbonate **$KHCO_3$**

Exercise 6.5 - Naming Binary Covalent Compounds: Write names that correspond to the following formulas: *(Obj 12)*

a. P_2O_5 **diphosphorus pentoxide**
b. PCl_3 **phosphorus trichloride**
c. CO **carbon monoxide**
d. H_2S **dihydrogen monosulfide or hydrogen sulfide**
e. NH_3 **ammonia**

Exercise 6.6 - Writing Formulas for Binary Covalent Compounds: Write formulas that correspond to the following names: *(Obj 12)*

a. disulfur decafluoride **S_2F_{10}**
b. nitrogen trifluoride **NF_3**
c. propane **C_3H_8**
d. hydrogen chloride **HCl**

Exercise 6.7 - Formulas for Acids: Write the chemical formulas that correspond to the names *(Obj 23)*

a. hydrofluoric acid
This name has the form of a binary acid, hydro(root)ic acid, so its formula is **HF(aq)**.

b. phosphoric acid
This name has the form of an oxyacid, (root)ic acid, so it contains hydrogen, phosphorus, and oxygen. Phosphate is PO_4^{3-}, so phosphoric acid is **H_3PO_4.**

Exercise 6.8 - Naming Acids: Write the names that correspond to the chemical formulas *(Obj 23)*

a. HI(*aq*)
This is a binary acid, so its name has the form hydro(root)ic acid. HI(aq) is **hydriodic acid**. *(The "o" in hydro- is usually left off.)*

b. $HC_2H_3O_2$.
The name of the oxyanion $C_2H_3O_2^-$ is acetate, so $HC_2H_3O_2$ is **acetic acid**. *CH_3CO_2H and CH_3COOH are also commonly used as formulas for acetic acid.*

Exercise 6.9 - Formulas to Names: Write the names that correspond to the following chemical formulas. *(Obj 25)*

a. AlF_3 **aluminum fluoride**
b. PF_3 **phosphorus trifluoride**
c. H_3PO_4 **phosphoric acid**
d. $CaCO_3$ **calcium carbonate**
e. $Ca(HSO_4)_2$ **calcium hydrogen sulfate**
f. $CuCl_2$ **copper(II) chloride**
g. NH_4F **ammonium fluoride**
h. HCl(*aq*) **hydrochloric acid**
i. $(NH_4)_3PO_4$ **ammonium phosphate**

Exercise 6.10 - Names to Formulas: Write the chemical formulas that correspond to the following names. *(Obj 25)*

a. ammonium nitrate **NH_4NO_3**
b. acetic acid **$HC_2H_3O_2$**
c. sodium hydrogen sulfate **$NaHSO_4$**
d. potassium bromide **KBr**
e. magnesium hydrogen phosphate **$MgHPO_4$**
f. hydrofluoric acid **HF(aq)**
g. diphosphorus tetroxide **P_2O_4**
h. aluminum carbonate **$Al_2(CO_3)_3$**
i. sulfuric acid **H_2SO_4**

Exercise 6.11 - Molecular Mass Calculations: A typical glass of wine contains about 16 g of ethanol, C_2H_5OH. *(Objs 26-28)*

a. What is the molecular mass of C_2H_5OH?

   2(12.011) + 6(1.00794) + 1(15.9994) = **46.069**

b. What is the mass of 1 mole of C_2H_5OH?

   46.069 g *(One mole of a molecular compound has a mass in grams equal to its molecular mass.)*

c. Write a conversion factor that will convert between mass and moles of C_2H_5OH.

$$\left(\frac{\mathbf{46.069\ g\ C_2H_5OH}}{\mathbf{1\ mol\ C_2H_5OH}}\right)$$

d. How many moles of ethanol are there in 16 grams of C_2H_5OH?

$$?\ \text{mol}\ C_2H_5OH = 16\ \text{g}\ C_2H_5OH\left(\frac{1\ \text{mol}\ C_2H_5OH}{46.069\ \text{g}\ C_2H_5OH}\right) = \mathbf{0.35\ mole\ C_2H_5OH}$$

e. What is the volume in milliliters of 1.0 mole of pure C_2H_5OH? (The density of ethanol is 0.7893 g/mL.)

$$?\ \text{mL}\ C_2H_5OH = 1.0\ \text{mol}\ C_2H_5OH\left(\frac{46.069\ \text{g}\ C_2H_5OH}{1\ \text{mol}\ C_2H_5OH}\right)\left(\frac{1\ \text{mL}\ C_2H_5OH}{0.7893\ \text{g}\ C_2H_5OH}\right)$$

$$= \mathbf{58\ mL\ C_2H_5OH}$$

Exercise 6.12 - Formula Mass Calculations: A quarter teaspoon of a typical baking powder contains about 0.4 g of sodium hydrogen carbonate, $NaHCO_3$. *(Objs 31-33)*

a. Calculate the formula mass of sodium hydrogen carbonate.

Formula Mass = 1(22.9898) + 1(1.00794) + 1(12.011) + 3(15.9994)

= 84.007

b. What is the mass in grams of 1 mole of $NaHCO_3$?

84.007 g *(One mole of an ionic compound has a mass in grams equal to its formula mass.)*

c. Write a conversion factor to convert between mass and moles of $NaHCO_3$.

$$\left(\frac{\mathbf{84.007\ g\ NaHCO_3}}{\mathbf{1\ mol\ NaHCO_3}}\right)$$

d. How many moles of $NaHCO_3$ are in 0.4 g of $NaHCO_3$?

$$?\ \text{mol NaHCO}_3 = 0.4\ \text{g NaHCO}_3\left(\frac{1\ \text{mol NaHCO}_3}{84.007\ \text{g NaHCO}_3}\right) = \mathbf{5 \times 10^{-3}\ mol\ NaHCO_3}$$

Exercise 6.13 - Molar Ratios of Element to Compound: Find the requested conversion factors. *(Objs 34 & 35)*

a. Write a conversion factor that converts between moles of hydrogen and moles of C_2H_5OH.

$$\frac{\mathbf{6\ mol\ H}}{\mathbf{1\ mol\ C_2H_5OH}}$$

b. Write a conversion factor that converts between moles of oxygen and moles of $NaHCO_3$.

$$\frac{\mathbf{3\ mol\ O}}{\mathbf{1\ mol\ NaHCO_3}}$$

c. How many moles of hydrogen carbonate ions, HCO_3^-, are there in 1 mole of $NaHCO_3$?

There is 1 mole of HCO_3^- per 1 mole of $NaHCO_3$.

Exercise 6.14 - Molar Mass Calculations: Disulfur dichloride, S_2Cl_2, is used in vulcanizing rubber and in 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? *(Obj 36)*

$$?\ \text{g S}_2\text{Cl}_2 = 123.8\ \text{g S}\left(\frac{1\ \text{mol S}}{32.066\ \text{g S}}\right)\left(\frac{1\ \text{mol S}_2\text{Cl}_2}{2\ \text{mol S}}\right)\left(\frac{135.037\ \text{g S}_2\text{Cl}_2}{1\ \text{mole S}_2\text{Cl}_2}\right) = \mathbf{260.7\ g\ S_2Cl_2}$$

Exercise 6.15 - Molar Mass Calculations: Vanadium metal, which is 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? *(Obj 36)*

$$?\ \text{kg V} = 2.3\ \text{kg V}_2\text{O}_5\left(\frac{10^3\ \text{g}}{1\ \text{kg}}\right)\left(\frac{1\ \text{mol V}_2\text{O}_5}{181.880\ \text{g V}_2\text{O}_5}\right)\left(\frac{2\ \text{mol V}}{1\ \text{mol V}_2\text{O}_5}\right)\left(\frac{50.9415\ \text{g V}}{1\ \text{mol V}}\right)\left(\frac{1\ \text{kg}}{10^3\ \text{g}}\right)$$

$$= \mathbf{1.3\ kg\ V}$$

Exercise 6.16 – Calculating an Empirical Formula: Bismuth ore, often called bismuth glance, contains an ionic compound that consists 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? *(Obj 37)*

$$? \text{ mol Bi} = 32.516 \text{ g Bi}\left(\frac{1 \text{ mol Bi}}{208.9804 \text{ g Bi}}\right) = 0.15559 \text{ mol Bi} \div 0.15559 = 1 \text{ mol Bi} \times 2 = 2 \text{ mol Bi}$$

$$? \text{ mol S} = 7.484 \text{ g S}\left(\frac{1 \text{ mol S}}{32.066 \text{ g S}}\right) = 0.2334 \text{ mol S} \div 0.15559 \cong 1\frac{1}{2} \text{ mol S} \times 2 = 3 \text{ mol S}$$

Our empirical formula is $\mathbf{Bi_2S_3}$ *or bismuth(III) sulfide.*

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? *(Obj 38)*

$$? \text{ mol K} = 35.172 \text{ g K}\left(\frac{1 \text{ mol K}}{39.0983 \text{ g K}}\right) = 0.89958 \text{ mol K} \div 0.89958 = 1 \text{ mol K} \times 2 = 2 \text{ mol K}$$

$$? \text{ mol S} = 28.846 \text{ g S}\left(\frac{1 \text{ mol S}}{32.066 \text{ g S}}\right) = 0.89958 \text{ mol S} \div 0.89958 = 1 \text{ mol S} \times 2 = 2 \text{ mol S}$$

$$? \text{ mol O} = 35.982 \text{ g O}\left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}}\right) = 2.2490 \text{ mol O} \div 0.89958 \cong 2\frac{1}{2} \text{ mol O} \times 2 = 5 \text{ mol O}$$

Empirical Formula $\mathbf{K_2S_2O_5}$

Exercise 6.18 – Calculating a Molecular Formula Using the Percentage of Each Element in a Compound: 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. This is a use for which no suitable substitute has been found. One PCB is 39.94% carbon, 1.12% hydrogen, and 58.94% chlorine and has a molecular mass of 360.88. What is its molecular formula? *(Objs 38 & 39)*

$$? \text{ mol C} = 39.94 \text{ g C}\left(\frac{1 \text{ mol C}}{12.011 \text{ g C}}\right) = 3.325 \text{ mol C} \div 1.11 = 3 \text{ mol C} \times 2 = 6 \text{ mol C}$$

$$? \text{ mol H} = 1.12 \text{ g H}\left(\frac{1 \text{ mol H}}{1.00794 \text{ g H}}\right) = 1.11 \text{ mol H} \div 1.11 = 1 \text{ mol H} \times 2 = 2 \text{ mol H}$$

$$? \text{ mol Cl} = 58.94 \text{ g Cl}\left(\frac{1 \text{ mol Cl}}{35.4527 \text{ g Cl}}\right) = 1.662 \text{ mol Cl} \div 1.11 \cong 1\frac{1}{2} \text{ mol Cl} \times 2 = 3 \text{ mol Cl}$$

Empirical Formula $C_6H_2Cl_3$ $\quad n = \frac{\text{molecular mass}}{\text{empirical formula mass}} = \frac{360.88}{180.440} \cong 2$

Molecular Formula $= (C_6H_2Cl_3)_2$ *or* $\mathbf{C_{12}H_4Cl_6}$

Review Questions Key

1. Classify each of the following as either an ionic compound or a molecular compound.
   a. $MgCl_2$ **ionic**
   b. PCl_3 **molecular**
   c. $KHSO_4$ **ionic**
   d. Na_2SO_4 **ionic**
   e. H_2SO_3 **molecular**
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 **+2**
   b. oxygen, O **–2**
   c. bromine, Br **–1**
   d. lithium, Li **+1**
   e. aluminum, Al **+3**
   f. nitrogen, N **–3**
3. Define the following terms.
   a. **Monatomic anions** *Negatively charged particles, such as* Cl^-, O^{2-}, *and* N^{3-}, *that contain single atoms with a negative charge.*
   b. **Monatomic cations** *Positively charged particles, such as* Na^+, Ca^{2+}, *and* Al^{3+}, *that contain single atoms with a positive charge.*
   c. **Polyatomic ion** *A charged collection of atoms held together by covalent bonds.*
4. Convert 37.625 g phosphorus, P, to moles.

$$? \text{ mol P} = 37.625 \text{ g P}\left(\frac{1 \text{ mol P}}{30.9738 \text{ g P}}\right) = \mathbf{1.2147\ mol\ P}$$

Key Ideas Answers

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) **specific type of compound**.
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 $\mathbf{H^+}$.
9. You can recognize binary covalent compounds from their formulas, which contain symbols for only two **nonmetallic** elements.
11. According to the modern form of the Arrhenius theory, an acid is a substance that produces **hydronium ions,** $\mathbf{H_3O^+}$, when it is added to water.
13. The binary acids have the general formula of HX(*aq*), where X is one of the first four **halogens**.
15. If each molecule of an acid can donate **one hydrogen ion**, the acid is called a monoprotic acid. A(n) **diprotic** acid, such as sulfuric acid, H_2SO_4, has two acidic hydrogen atoms.
17. 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.

19. The chemical equations for completion reactions are written with **single** arrows to indicate that the reaction proceeds to form almost 100% products.
21. If enough H^+ ions are added to a(n) **root(ate)** polyatomic ion to completely neutralize its charge, the (root)ic acid is formed.
23. In this text, the term **formula unit** 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 **kinds** and **numbers** of atoms or ions listed in the chemical formula.
25. We can convert between moles of element and moles of a compound containing that element by using the molar ratio derived from the **formula** for the compound.
27. A molecular formula describes the actual numbers of **atoms** in a molecule.

Problems Key

Section 6.1 Ionic Nomenclature

29. Write the name for each of these monatomic ions. *(Obj 2)*

a. Ca^{2+} **calcium ion**
b. Li^+ **lithium ion**
c. Cr^{2+} **chromium(II) ion**
d. F^- **fluoride ion**
e. Ag^+ **silver ion or silver(I) ion**
f. Sc^{3+} **scandium ion**
g. P^{3-} **phosphide ion**
h. Pb^{2+} **lead(II) ion**

31. Write the formula for each of these monatomic ions. *(Obj 2)*

a. magnesium ion **Mg^{2+}**
b. sodium ion **Na^+**
c. sulfide ion **S^{2-}**
d. iron(III) ion **Fe^{3+}**
e. scandium ion **Sc^{3+}**
f. nitride ion **N^{3-}**
g. manganese(III) ion **Mn^{3+}**
h. zinc ion **Zn^{2+}**

33. Write the name for each of these polyatomic ions. *(Obj 4)*

a. NH_4^+ **ammonium**
b. $C_2H_3O_2^-$ **acetate**
c. HSO_4^- **hydrogen sulfate**

35. Write the formula for each of these polyatomic ions. *(Obj 4)*

a. ammonium **NH_4^+**
b. bicarbonate ion **HCO_3^-**
c. hydrogen sulfate ion **HSO_4^-**

36. Write the name for each of these chemical formulas. *(Obj 7)*

a. Na_2O (a dehydrating agent) **sodium oxide**
b. Ni_2O_3 (in storage batteries) **nickel(III) oxide**
c. $Pb(NO_3)_2$ (in matches and explosives) **lead(II) nitrate**
d. $Ba(OH)_2$ (an analytical reagent) **barium hydroxide**
e. $KHCO_3$ (in baking powder and fire-extinguishing agents) **potassium hydrogen carbonate**

38. Write the chemical formula for each of the following names. *(Obj 7)*
    a. potassium sulfide (a depilatory) **K_2S**
    b. zinc phosphide (a rodenticide) **Zn_3P_2**
    c. nickel(II) chloride (used in nickel electroplating) **$NiCl_2$**
    d. magnesium dihydrogen phosphate (used in fireproofing wood) **$Mg(H_2PO_4)_2$**
    e. lithium bicarbonate (in mineral waters) **$LiHCO_3$**

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. *(Obj 7)*

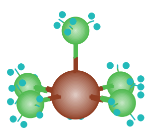
    copper(II) fluoride (CuF_2), ammonium chloride (NH_4Cl), cadmium oxide (CdO), and mercury(II) sulfate ($HgSO_4$)

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. *(Obj 7)*

    copper(II) chloride ($CuCl_2$), lithium nitrate ($LiNO_3$), and cadmium sulfide (CdS)

Section 6.2 Binary Covalent Nomenclature

45. The compound represented by the ball-and-stick model that follows 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.



BrF_5 – bromine pentafluoride

47. The compound represented by the space-filling model that follows 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 chlorine atoms. List the sulfur atom first in the chemical formula.

SCl_2 – sulfur dichloride

49. Write the name for each of the following chemical formulas. *(Objs 8, 11, and 12)*
    a. I_2O_5 (an oxidizing agent) **diiodine pentoxide**
    b. BrF_3 (adds fluorine atoms to other compounds) **bromine trifluoride**
    c. IBr (used in organic synthesis) **iodine monobromide**
    d. CH_4 (a primary component of natural gas) **methane**
    e. HBr (used to make pharmaceuticals) **hydrogen bromide or hydrogen monobromide**

51. Write the chemical formula for each of the following names. *(Objs 8, 11, and 12)*
    a. propane (a fuel in heating torches) **C_3H_8**
    b. chlorine monofluoride (a fluorinating agent) **ClF**
    c. tetraphosphorus heptasulfide (a dangerous fire risk) **P_4S_7**
    d. carbon tetrabromide (used to make organic compounds) **CBr_4**
    e. hydrogen fluoride (an additive to liquid rocket propellants) **HF**

Section 6.3 Acids

53. Describe how the strong monoprotic acid nitric acid, HNO_3(*aq*) (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. *(Obj 14)*

    When HNO_3 molecules dissolve in water, each HNO_3 molecule donates a proton, H^+, to water forming hydronium ion, H_3O^+, and nitrate ion, NO_3^-. This reaction goes to completion, and the solution of the HNO_3 contains essentially no uncharged acid molecules. Once the nitrate 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 nitrate ion. If you substitute nitrate ions, NO_3^-, for chloride ions, Cl^-, Figure 6.2 shows you how you can picture this solution.

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. *(Obj 21)*

    Each sulfuric acid molecule loses its first hydrogen ion completely.

    $$H_2SO_4(aq) + H_2O(l) \rightarrow H_3O^+(aq) + HSO_4^-(aq)$$

    The second hydrogen ion is not lost completely.

    $$HSO_4^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$$

    In a typical solution of sulfuric acid, for each 100 sulfuric acid molecules added to water, the solution contains about 101 hydronium ions, H_3O^+, 99 hydrogen sulfate ions, HSO_4^-, and 1 sulfate ion, SO_4^{2-}.

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. *(Obj 18)*

    A weak acid is a substance that is incompletely ionized in water due to a reversible reaction with water that forms hydronium ion, H_3O^+. A strong acid is a substance that is completely ionized in water due to a completion reaction with water that forms hydronium ions, H_3O^+.

59. Identify each of the following as a strong or a weak acid. *(Obj 22)*

    a. sulfurous acid (for bleaching straw) **weak**
    b. H_2SO_4 (used to make plastics) **strong**
    c. oxalic acid (in car radiator cleaners) **weak**

61. Identify each of the following as a strong or a weak acid. *(Obj 22)*

    a. H_3PO_4 (added to animal feeds) **weak**
    b. hypophosphorous acid (in electroplating baths) **weak**
    c. HF(*aq*) (used to process uranium) **weak**

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

    a. The monoprotic weak acid nitrous acid, HNO_2

    $$HNO_2(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NO_2^-(aq)$$

    b. The monoprotic strong acid hydrobromic acid, HBr

    $$HBr(aq) + H_2O(l) \rightarrow H_3O^{\square}(aq) + Br^-(aq)$$

Section 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.
    a. NO_3^- **HNO_3 nitric acid**
    b. CO_3^{2-} **H_2CO_3 carbonic acid**
    c. PO_4^{3-} **H_3PO_4 phosphoric acid**

67. Classify each of the following compounds as (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. *(Objs 23-25)*
    a. phosphoric acid **oxyacid H_3PO_4**
    b. ammonium bromide **ionic compound with polyatomic ion NH_4Br**
    c. diphosphorus tetriodide **binary covalent compound P_2I_4**
    d. lithium hydrogen sulfate **ionic compound with polyatomic ion $LiHSO_4$**
    e. hydrochloric acid **binary acid HCl(aq)**
    f. magnesium nitride **binary ionic compound Mg_3N_2**
    g. acetic acid **oxyacid $HC_2H_3O_2$**
    h. lead(II) hydrogen phosphate **ionic compound with polyatomic ion $PbHPO_4$**

69. Classify each of the following formulas as (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. *(Objs 23-25)*
    a. HBr(*aq*) **binary acid hydrobromic acid**
    b. ClF_3 **binary covalent compound chlorine trifluoride**
    c. $CaBr_2$ **binary ionic compound calcium bromide**
    d. $Fe_2(SO_4)_3$ **ionic compound with polyatomic ion iron(III) sulfate**
    e. H_2CO_3 **oxyacid carbonic acid**
    f. $(NH_4)_2SO_4$ **ionic compound with polyatomic ion ammonium sulfate**
    g. $KHSO_4$ **ionic compound with polyatomic ion potassium hydrogen sulfate**

Section 6.6 Molar Mass and Chemical Compounds

71. For each of the following molecular substances, calculate its molecular mass and write a conversion factor that converts between mass in grams and moles of the substance. *(Objs 26 & 27)*
    a. H_3PO_2

$$\textit{molecular mass } H_3PO_2 = 3(1.00794) + 1(30.9738) + 2(15.9994)$$

$$= \mathbf{65.9964} \ \textit{leads to} \ \left(\frac{\mathbf{65.9964\ g\ H_3PO_2}}{\mathbf{1\ mol\ H_3PO_2}}\right)$$

    b. $C_6H_5NH_2$

$$\textit{molecular mass } C_6H_5NH_2 = 6(12.011) + 7(1.00794) + 1(14.0067)$$

$$= \mathbf{93.128} \ \textit{leads to} \ \left(\frac{\mathbf{93.128\ g\ C_6H_5NH_2}}{\mathbf{1\ mol\ C_6H_5NH_2}}\right)$$

73. Each dose of nighttime cold medicine contains 1000 mg of the analgesic acetaminophen. Acetaminophen, or N-acetyl-p-aminophenol, has the general formula C_8H_9NO. *(Obj 28)*

a. How many moles of acetaminophen are in each dose?

$$? \text{ mol } C_8H_9NO = 1000 \text{ mg } C_8H_9NO \left(\frac{1 \text{ g}}{10^3 \text{ mg}}\right)\left(\frac{1 \text{ mol } C_8H_9NO}{135.166 \text{ g } C_8H_9NO}\right)$$

$$\mathbf{= 7.398 \times 10^{-3} \text{ mol } C_8H_9NO}$$

b. What is the mass in grams of 15.0 moles of acetaminophen?

$$? \text{ g } C_8H_9NO = 15.0 \text{ mol } C_8H_9NO \left(\frac{135.166 \text{ g } C_8H_9NO}{1 \text{ mol } C_8H_9NO}\right) \mathbf{= 2.03 \times 10^3 \text{ g } C_8H_9NO}$$

76. For each of the following examples, decide whether it would be better to use the term *molecule* or *formula unit*. *(Obj 30)*

a. Cl_2O **molecular compound - molecules**
b. Na_2O **ionic compound – formula units**
c. $(NH_4)_2SO_4$ **ionic compound – formula units**
d. $HC_2H_3O_2$ **molecular compound - molecules**

78. For each of the following ionic substances, calculate its formula mass and write a conversion factor that converts between mass in grams and moles of the substance. *(Objs 31 & 32)*

a. $BiBr_3$

formula mass $BiBr_3$ = 1(208.9804) + 3(79.904)

$$= \mathbf{448.69} \ \textit{leads to} \ \left(\frac{\mathbf{448.69 \text{ g } BiBr_3}}{\mathbf{1 \text{ mol } BiBr_3}}\right)$$

b. $Al_2(SO_4)_3$

formula mass $Al_2(SO_4)_3$ = 2(26.9815) + 3(32.066) + 12(15.9994)

$$= \mathbf{342.154} \ \textit{leads to} \ \left(\frac{\mathbf{342.154 \text{ g } Al_2(SO_4)_3}}{\mathbf{1 \text{ mol } Al_2(SO_4)_3}}\right)$$

80. A common antacid tablet contains 500 mg of calcium carbonate, $CaCO_3$. *(Obj 33)*

a. How many moles of $CaCO_3$ does each tablet contain?

$$? \text{ mol } CaCO_3 = 500 \text{ mg } CaCO_3 \left(\frac{1 \text{ g}}{10^3 \text{ mg}}\right)\left(\frac{1 \text{ mol } CaCO_3}{100.087 \text{ g } CaCO_3}\right)$$

$$\mathbf{= 5.00 \times 10^{-3} \text{ mol } CaCO_3}$$

b. What is the mass in kilograms of 100.0 moles of calcium carbonate?

$$? \text{ kg } CaCO_3 = 100.0 \text{ mol } CaCO_3 \left(\frac{100.087 \text{ g } CaCO_3}{1 \text{ mol } CaCO_3}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right)$$

$$\mathbf{= 10.01 \text{ kg } CaCO_3}$$

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.) *(Obj 33)*

$$? \text{ mol } Al_2O_3 = 0.78 \text{ carat } Al_2O_3 \left(\frac{1 \text{ g}}{5 \text{ carats}}\right)\left(\frac{1 \text{ mol } Al_2O_3}{101.9612 \text{ g } Al_2O_3}\right) \mathbf{= 1.5 \times 10^{-3} \text{ mol } Al_2O_3}$$

Section 6.7 Relationships 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. *(Obj 34)*

$$\frac{\mathbf{2\,mol\,N}}{\mathbf{1\,mol\,N_2O_5}}$$

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. *(Obj 35)*

$$\frac{\mathbf{2\,mol\,Cr}}{\mathbf{1\,mol\,Cr_2O_3}}$$

88. Ammonium oxalate is used for stain and rust removal. How many moles of ammonium ions are in one mole of ammonium oxalate, $(NH_4)_2C_2O_4$? *(Obj 35)*

There are **two moles of ammonium ions** *in one mole of* $(NH_4)_2C_2O_4$.

90. A nutritional supplement contains 0.405 g of $CaCO_3$. The recommended daily value of calcium is 1.000 g Ca. *(Objs 34 & 36)*

a. Write a conversion factor that relates moles of calcium to moles of calcium carbonate.

$$\left(\frac{\mathbf{1\,mol\,Ca}}{\mathbf{1\,mol\,CaCO_3}}\right)$$

b. Calculate the mass in grams of calcium in 0.405 g of $CaCO_3$.

$$?\text{ g Ca} = 0.405\text{ g CaCO}_3\left(\frac{1\text{ mol CaCO}_3}{100.087\text{ g CaCO}_3}\right)\left(\frac{1\text{ mol Ca}}{1\text{ mol CaCO}_3}\right)\left(\frac{40.078\text{ g Ca}}{1\text{ mol Ca}}\right)$$

= 0.162 g Ca

c. What percentage of the daily value of calcium comes from this tablet?

$$\%\text{ Ca} = \frac{0.162\text{ g Ca in supp.}}{1.000\text{ g Ca total}}\times 100\quad \mathbf{= 16.2\%\ of\ daily\ value\ Ca}$$

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? *(Obj 36)*

$$?\ \mu\text{g NaVO}_3 = 10\ \mu\text{g V}\left(\frac{1\text{ g}}{10^6\ \mu\text{g}}\right)\left(\frac{1\text{ mol V}}{50.9415\text{ g V}}\right)\left(\frac{1\text{ mol NaVO}_3}{1\text{ mol V}}\right)\left(\frac{121.9295\text{ g NaVO}_3}{1\text{ mol NaVO}_3}\right)\left(\frac{10^6\ \mu\text{g}}{1\text{ g}}\right)$$

= 24 μg $NaVO_3$

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 $TiCl_4$? *(Obj 36)*

$$?\text{ kg Ti} = 0.401\text{ Mg TiCl}_4\left(\frac{10^6\text{ g}}{1\text{ Mg}}\right)\left(\frac{1\text{ mol TiCl}_4}{189.678\text{ g TiCl}_4}\right)\left(\frac{1\text{ mol Ti}}{1\text{ mol TiCl}_4}\right)\left(\frac{47.867\text{ g Ti}}{1\text{ mol Ti}}\right)\left(\frac{1\text{ kg}}{10^3\text{ g}}\right)$$

= 101 kg Ti

Section 6.8 Determination of Empirical and Molecular Formulas

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? *(Obj 37)*

$$? \text{ mol Ag} = 17.261 \text{ g Ag}\left(\frac{1 \text{ mol Ag}}{107.8682 \text{ g Ag}}\right) = 0.16002 \text{ mol Ag} \div 0.0530 \cong 3 \text{ mol Ag}$$

$$? \text{ mol N} = 0.743 \text{ g N}\left(\frac{1 \text{ mol N}}{14.0067 \text{ g N}}\right) = 0.0530 \text{ mol N} \div 0.0530 = 1 \text{ mol N}$$

Empirical Formula **Ag_3N** **silver nitride**

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? *(Obj 37)*

$$? \text{ mol Ca} = 9.2402 \text{ g Ca}\left(\frac{1 \text{ mol Ca}}{40.078 \text{ g Ca}}\right) = 0.23056 \text{ mol Ca} \div 0.23056 = 1 \text{ mol Ca} \times 2 = 2 \text{ mol Ca}$$

$$? \text{ mol P} = 7.2183 \text{ g P}\left(\frac{1 \text{ mol P}}{30.9738 \text{ g P}}\right) = 0.23305 \text{ mol P} \div 0.23056 \cong 1 \text{ mol P} \times 2 = 2 \text{ mol P}$$

$$? \text{ mol O} = 13.0512 \text{ g O}\left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}}\right) = 0.815731 \text{ mol O} \div 0.23056 \cong 3\frac{1}{2} \text{ mol O} \times 2 = 7 \text{ mol O}$$

Empirical Formula **$Ca_2P_2O_7$**

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? *(Obj 38)*

$$? \text{ mol Ni} = 38.791 \text{ g Ni}\left(\frac{1 \text{ mol Ni}}{58.6934 \text{ g Ni}}\right) = 0.66091 \text{ mol Ni} \div 0.44061 = 1\frac{1}{2} \text{ mol Ni} \times 2 = 3 \text{ mol Ni}$$

$$? \text{ mol As} = 33.011 \text{ g As}\left(\frac{1 \text{ mol As}}{74.9216 \text{ g As}}\right) = 0.44061 \text{ mol As} \div 0.44061 = 1 \text{ mol As} \times 2 = 2 \text{ mol As}$$

$$? \text{ mol O} = 28.198 \text{ g O}\left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}}\right) = 1.7624 \text{ mol O} \div 0.44061 \cong 4 \text{ mol O} \times 2 = 8 \text{ mol O}$$

Empirical Formula **$Ni_3As_2O_8$**

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? *(Obj 38)*

$$? \text{ mol Ca} = 10.279 \text{ g Ca}\left(\frac{1 \text{ mol Ca}}{40.078 \text{ g Ca}}\right) = 0.25647 \text{ mol Ca} \div 0.25647 = 1 \text{ mol Ca}$$

$$? \text{ mol I} = 65.099 \text{ g I}\left(\frac{1 \text{ mol I}}{126.9045 \text{ g I}}\right) = 0.51298 \text{ mol I} \div 0.25647 \cong 2 \text{ mol I}$$

$$? \text{ mol O} = 24.622 \text{ g O}\left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}}\right) = 1.5389 \text{ mol O} \div 0.25647 = 6 \text{ mol O}$$

Empirical Formula **CaI_2O_6 or $Ca(IO_3)_2$ calcium iodate**

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? *(Obj 38)*

Molecular Formula = (Empirical Formula)$_n$

$$n = \frac{\text{molecular mass}}{\text{empirical formula mass}} = \frac{60.099}{30.049} \cong 2$$

Molecular Formula = $(CNH_4)_2$ or **$C_2N_2H_8$**

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? *(Objs 38 & 39)*

$$? \text{ mol C} = 24.78 \text{ g C}\left(\frac{1 \text{ mol C}}{12.011 \text{ g C}}\right) = 2.063 \text{ mol C} \div 2.063 = 1 \text{ mol C}$$

$$? \text{ mol H} = 2.08 \text{ g H}\left(\frac{1 \text{ mol H}}{1.00794 \text{ g H}}\right) = 2.064 \text{ mol H} \div 2.063 \cong 1 \text{ mol H}$$

$$? \text{ mol Cl} = 73.14 \text{ g Cl}\left(\frac{1 \text{ mol Cl}}{35.4527 \text{ g Cl}}\right) = 2.063 \text{ mol Cl} \div 2.063 = 1 \text{ mol Cl}$$

Empirical Formula CHCl

$$n = \frac{\text{molecular mass}}{\text{empirical formula mass}} = \frac{290.830}{48.472} \cong 6$$

Molecular Formula = $(CHCl)_6$ or **$C_6H_6Cl_6$**

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? *(Objs 38 & 39)*

$$? \text{ mol C} = 28.57 \text{ g C}\left(\frac{1 \text{ mol C}}{12.011 \text{ g C}}\right) = 2.379 \text{ mol C} \div 2.379 = 1 \text{ mol C}$$

$$? \text{ mol H} = 4.80 \text{ g H}\left(\frac{1 \text{ mol H}}{1.00794 \text{ g H}}\right) = 4.76 \text{ mol H} \div 2.379 \cong 2 \text{ mol H}$$

$$? \text{ mol N} = 66.63 \text{ g N}\left(\frac{1 \text{ mol N}}{14.0067 \text{ g N}}\right) = 4.757 \text{ mol N} \div 2.379 \cong 2 \text{ mol N}$$

Empirical Formula CH_2N_2

$$n = \frac{\text{molecular mass}}{\text{empirical formula mass}} = \frac{126.121}{42.040} \cong 3$$

Molecular Formula = $(CH_2N_2)_3$ *or* $\mathbf{C_3H_6N_6}$

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?

weighted average = 0.07(2.65 g) + 0.04(2.75 g) + 0.89(2.90 g) = **2.88 g**

$$? \text{ screws} = 68 \text{ lb screws}\left(\frac{453.6 \text{ g}}{1 \text{ lb}}\right)\left(\frac{1 \text{ screw}}{2.88 \text{ g}}\right) = \mathbf{1.1 \times 10^4 \text{ screws}}$$

$$? \text{ screws} = 68 \text{ lb screws}\left(\frac{453.6 \text{ g}}{1 \text{ lb}}\right)\left(\frac{1 \text{ screw}}{2.88 \text{ g}}\right)\left(\frac{1 \text{ gross screws}}{144 \text{ screws}}\right) = \mathbf{74 \text{ gross screws}}$$

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.)

$$? \text{ mol } Al_2O_3 = 2302 \text{ carat } Al_2O_3\left(\frac{1 \text{ g}}{5 \text{ carats}}\right)\left(\frac{1 \text{ mol } Al_2O_3}{101.9612 \text{ g } Al_2O_3}\right) = \mathbf{4.515 \text{ mol} Al_2O_3}$$

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 $Be_3Al_2(SiO_3)_6$. 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 $Be_3Al_2(SiO_3)_6$, how many moles of beryllium would it contain?

$$? \text{ mol } Be_3Al_2(SiO_3)_6 = 43 \text{ lb } Be_3Al_2(SiO_3)_6 \left(\frac{453.6 \text{ g}}{1 \text{ lb}}\right)\left(\frac{1 \text{ mol } Be_3Al_2(SiO_3)_6}{537.502 \text{ g } Be_3Al_2(SiO_3)_6}\right)\left(\frac{3 \text{ mol Be}}{1 \text{ mol } Be_3Al_2(SiO_3)_6}\right) = \mathbf{1.1 \times 10^2 \text{ mol Be}}$$

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.)

$$? \text{ carat } SiO_2 = 0.040 \text{ mol } SiO_2 \left(\frac{60.0843 \text{ g } SiO_2}{1 \text{ mol } SiO_2}\right)\left(\frac{5 \text{ carat}}{1 \text{ g}}\right) = \mathbf{12 \text{ carats}}$$

119. A common throat lozenge contains 29 mg of phenol, C_6H_5OH.

a. How many moles of C_6H_5OH are there in 5.0 mg of phenol?

$$? \text{ mol } C_6H_5OH = 5.0 \text{ mg } C_6H_5OH \left(\frac{1 \text{ g}}{10^3 \text{ mg}}\right)\left(\frac{1 \text{ mol } C_6H_5OH}{94.113 \text{ g } C_6H_5OH}\right) = \mathbf{5.3 \times 10^{-5} \text{ mol } C_6H_5OH}$$

b. What is the mass in kilograms of 0.9265 mole of phenol?

$$? \text{ kg } C_6H_5OH = 0.9265 \text{ mol } C_6H_5OH \left(\frac{94.113 \text{ g } C_6H_5OH}{1 \text{ mol } C_6H_5OH}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right) = \mathbf{0.08720 \text{ kg } C_6H_5OH}$$

121. Beryl, $Be_3Al_2(SiO_3)_6$, is a natural source of beryllium, a known carcinogen. What is the mass in kilograms of beryllium in 1.006 Mg of $Be_3Al_2(SiO_3)_6$?

$$? \text{ kg Be} = 1.006 \text{ Mg } Be_3Al_2(SiO_3)_6 \left(\frac{10^6 \text{ g}}{1 \text{ Mg}}\right)\left(\frac{1 \text{ mol } Be_3Al_2(SiO_3)_6}{537.502 \text{ g } Be_3Al_2(SiO_3)_6}\right)\left(\frac{3 \text{ mol Be}}{1 \text{ mol } Be_3Al_2(SiO_3)_6}\right)\left(\frac{9.0122 \text{ g Be}}{1 \text{ mol Be}}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right) = \mathbf{50.60 \text{ kg Be}}$$

123. Cermets (for *cer*amic plus *met*al) 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?

$$? \text{ mol Mo} = 14.212 \text{ g Mo} \left(\frac{1 \text{ mol Mo}}{95.94 \text{ g Mo}}\right) = 0.1481 \text{ mol Mo} \div 0.1481 = 1 \text{ mol Mo}$$

$$? \text{ mol Si} = 8.321 \text{ g Si} \left(\frac{1 \text{ mol Si}}{28.0855 \text{ g Si}}\right) = 0.2963 \text{ mol Si} \div 0.1481 \cong 2 \text{ mol Si}$$

Empirical Formula $\mathbf{MoSi_2}$

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?

$$? \text{ mol K} = 30.52 \text{ g K}\left(\frac{1 \text{ mol K}}{39.0983 \text{ g K}}\right) = 0.7806 \text{ mol K} \div 0.7806 = 1 \text{ mol K}$$

$$? \text{ mol H} = 0.787 \text{ g H}\left(\frac{1 \text{ mol H}}{1.00794 \text{ g H}}\right) = 0.781 \text{ mol H} \div 0.7806 \cong 1 \text{ mol H}$$

$$? \text{ mol C} = 18.75 \text{ g C}\left(\frac{1 \text{ mol C}}{12.011 \text{ g C}}\right) = 1.561 \text{ mol C} \div 0.7806 \cong 2 \text{ mol C}$$

$$? \text{ mol O} = 49.95 \text{ g O}\left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}}\right) = 3.122 \text{ mol O} \div 0.7806 \cong 4 \text{ mol O}$$

Empirical Formula $\mathbf{KHC_2O_4}$

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?

$$? \text{ mol Na} = 24.186 \text{ g Na}\left(\frac{1 \text{ mol Na}}{22.9898 \text{ g Na}}\right) = 1.0520 \text{ mol Na} \div 1.0520 = 1 \text{ mol Na} \times 2 = 2 \text{ mol Na}$$

$$? \text{ mol S} = 33.734 \text{ g S}\left(\frac{1 \text{ mol S}}{32.066 \text{ g S}}\right) = 1.0520 \text{ mol S} \div 1.0520 \cong 1 \text{ mol S} \times 2 = 2 \text{ mol S}$$

$$? \text{ mol O} = 42.080 \text{ g O}\left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}}\right) = 2.6301 \text{ mol O} \div 1.0520 = 2\frac{1}{2} \text{ mol O} \times 2 = 5 \text{ mol O}$$

Empirical Formula $\mathbf{Na_2S_2O_5}$

129. An ionic compound 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.)

$$? \text{ mol Mn} = 22.071 \text{ g Mn}\left(\frac{1 \text{ mol Mn}}{54.9380 \text{ g Mn}}\right) = 0.40174 \text{ mol Mn} \div 0.40174 = 1 \text{ mol Mn}$$

$$? \text{ mol H} = 1.620 \text{ g H}\left(\frac{1 \text{ mol H}}{1.00794 \text{ g H}}\right) = 1.607 \text{ mol H} \div 0.40174 \cong 4 \text{ mol H}$$

$$? \text{ mol P} = 24.887 \text{ g P}\left(\frac{1 \text{ mol P}}{30.9738 \text{ g P}}\right) = 0.80349 \text{ mol P} \div 0.40174 \cong 2 \text{ mol P}$$

$$? \text{ mol O} = 51.422 \text{ g O}\left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}}\right) = 3.2140 \text{ mol O} \div 0.40174 \cong 8 \text{ mol O}$$

Empirical Formula $\mathbf{MnH_4P_2O_8}$ *or* $\mathbf{Mn(H_2PO_4)_2}$ *manganese(II) dihydrogen phosphate*

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?

$$? \text{ mol C} = 60.47 \text{ g C}\left(\frac{1 \text{ mol C}}{12.011 \text{ g C}}\right) = 5.035 \text{ mol C} \div 0.7746 = 6.5 \text{ mol C} \times 2 = 13 \text{ mol C}$$

$$? \text{ mol H} = 3.90 \text{ g H}\left(\frac{1 \text{ mol H}}{1.00794 \text{ g H}}\right) = 3.87 \text{ mol H} \div 0.7746 \cong 5 \text{ mol H} \times 2 = 10 \text{ mol H}$$

$$? \text{ mol O} = 24.78 \text{ g O}\left(\frac{1 \text{ mol O}}{15.9994 \text{ g O}}\right) = 1.549 \text{ mol O} \div 0.7746 \cong 2 \text{ mol O} \times 2 = 4 \text{ mol O}$$

$$? \text{ mol N} = 10.85 \text{ g N}\left(\frac{1 \text{ mol N}}{14.0067 \text{ g N}}\right) = 0.7746 \text{ mol N} \div 0.7746 = 1 \text{ mol N} \times 2 = 2 \text{ mol N}$$

Empirical Formula $C_{13}H_{10}O_4N_2$

$$n = \frac{\text{molecular mass}}{\text{empirical formula mass}} = \frac{258.23}{258.23} = 1$$

Molecular Formula = $\mathbf{C_{13}H_{10}O_4N_2}$

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?

$$? \text{ kg Zn} = 1.347 \times 10^4 \text{ kg calamine}\left(\frac{67.5 \text{ kg ZnO}}{100 \text{ kg calamine}}\right)\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol ZnO}}{81.39 \text{ g ZnO}}\right)\left(\frac{1 \text{ mol Zn}}{1 \text{ mol ZnO}}\right)\left(\frac{65.39 \text{ g Zn}}{1 \text{ mol Zn}}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right) = \mathbf{7.30 \times 10^3 \text{ kg Zn}}$$

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?

$$? \text{ kg As} = 67.3 \text{ kg flue dust}\left(\frac{93 \text{ kg } As_2O_3}{100 \text{ kg flue dust}}\right)\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol } As_2O_3}{197.841 \text{ g } As_2O_3}\right)\left(\frac{2 \text{ mol As}}{1 \text{ mol } As_2O_3}\right)\left(\frac{74.9216 \text{ g As}}{1 \text{ mol As}}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right)$$

or

$$? \text{ kg As} = 67.3 \text{ kg flue dust}\left(\frac{93 \text{ kg } As_2O_3}{100 \text{ kg flue dust}}\right)\left(\frac{2 \times 74.9216 \text{ g As}}{197.841 \text{ g } As_2O_3}\right) = \mathbf{47 \text{ kg As}}$$

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.

a. Magnesium ions can be precipitated from seawater as magnesium hydroxide, $Mg(OH)_2$. 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?

$$? \text{ t Mg} = 1.0 \times 10^5 \text{ kL seawater}\left(\frac{3.0 \text{ kg Mg(OH)}_2}{1 \text{ kL seawater}}\right)\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol Mg(OH)}_2}{58.3197 \text{ g Mg(OH)}_2}\right)$$
$$\left(\frac{1 \text{ mol Mg}}{1 \text{ mol Mg(OH)}_2}\right)\left(\frac{24.3050 \text{ g Mg}}{1 \text{ mol Mg}}\right)\left(\frac{1 \text{ t}}{10^6 \text{ g}}\right) = \mathbf{1.3 \times 10^2 \text{ t Mg}}$$

b. Brucite is a natural form of magnesium hydroxide. A typical crude ore containing brucite is 29% $Mg(OH)_2$. What minimum mass, in metric tons, of this crude ore is necessary to make 34.78 metric tons of magnesium metal?

$$? \text{ t ore} = 34.78 \text{ t Mg}\left(\frac{10^6 \text{ g}}{1 \text{ t}}\right)\left(\frac{1 \text{ mol Mg}}{24.3050 \text{ g Mg}}\right)\left(\frac{1 \text{ mol Mg(OH)}_2}{1 \text{ mol Mg}}\right)$$
$$\left(\frac{58.3197 \text{ g Mg(OH)}_2}{1 \text{ mol Mg(OH)}_2}\right)\left(\frac{1 \text{ t}}{10^6 \text{ g}}\right)\left(\frac{100 \text{ t ore}}{29 \text{ t Mg(OH)}_2}\right) = \mathbf{2.9 \times 10^2 \text{ t ore}}$$

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?

$$? \text{ t ore} = 2.4 \text{ t F}\left(\frac{10^6 \text{ g}}{1 \text{ t}}\right)\left(\frac{1 \text{ mol F}}{18.9984 \text{ g F}}\right)\left(\frac{1 \text{ mol CaF}_2}{2 \text{ mol F}}\right)\left(\frac{78.075 \text{ g CaF}_2}{1 \text{ mol CaF}_2}\right)\left(\frac{1 \text{ t}}{10^6 \text{ g}}\right)\left(\frac{100 \text{ t ore}}{72 \text{ t CaF}_2}\right)$$
$$= \mathbf{6.8 \text{ t ore}}$$

141. What mass of baking powder that is 36% $NaHCO_3$ contains 1.0 mole of sodium hydrogen carbonate?

$$? \text{ g baking powder} = 1.0 \text{ mol NaHCO}_3\left(\frac{84.007 \text{ g NaHCO}_3}{1 \text{ mol NaHCO}_3}\right)\left(\frac{100 \text{ g baking powder}}{36 \text{ g NaHCO}_3}\right)$$
$$= \mathbf{2.3 \times 10^2 \text{ g baking powder}}$$

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?

$$? \text{ t sand} = 120.5 \text{ kg Hf} \left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol Hf}}{178.49 \text{ g Hf}}\right)\left(\frac{1 \text{ mol HfO}_2}{1 \text{ mol Hf}}\right)\left(\frac{210.49 \text{ g HfO}_2}{1 \text{ mol HfO}_2}\right)$$

$$\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right)\left(\frac{100 \text{ kg sand}}{1.3 \text{ kg HfO}_2}\right)\left(\frac{1 \text{ t}}{10^3 \text{ kg}}\right) = \mathbf{11 \text{ t zircon sand}}$$