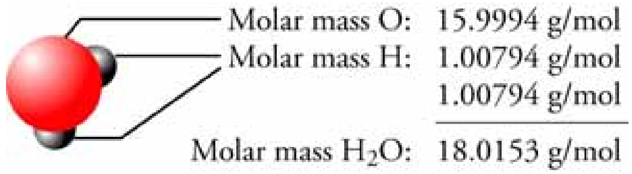
# Chapter 9
# Chemical Calculations and Chemical Formulas






## Section Goals and Introductions

### Section 9.1 A Typical Problem

*Goal: To introduce the chapter by describing a typical problem that you will be able to work after studying the chapter.*

Sometimes a task becomes much easier if you know from the beginning where you are going to end up. It will help you to understand the importance of Sections 9.2 and 9.3 if you first know how the calculations described there can be used. This section shows a typical problem and gives you a sense of why it is important.

**Section 9.2 Relating Mass to Number of Particles**

*Goals*

- *To show how to do a procedure called counting by weighing.*
- *To introduce atomic mass and show how it can be used to convert between the mass of a sample of an element and the number of atoms that the sample contains.*

Even a tiny sample of an element contains a huge number of atoms. There's no way that you could ever count that high, even if you were able to count atoms one at a time (which you can't). So if you want to know the number of atoms in a sample of an element, you have to do it by an indirect technique called *counting by weighing*. This section introduces this technique and shows how it can be applied to the conversions between mass of a sample of an element and the number of atoms in the sample. An important unit called the mole is introduced in this section. It is very important that you understand what it is and how it is used.

**Section 9.3 Molar Mass and Chemical Compounds**

*Goal: 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.

*Internet: Molar Mass Conversion Factors*

**Section 9.4 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 Section 9.2 and 9.3 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*

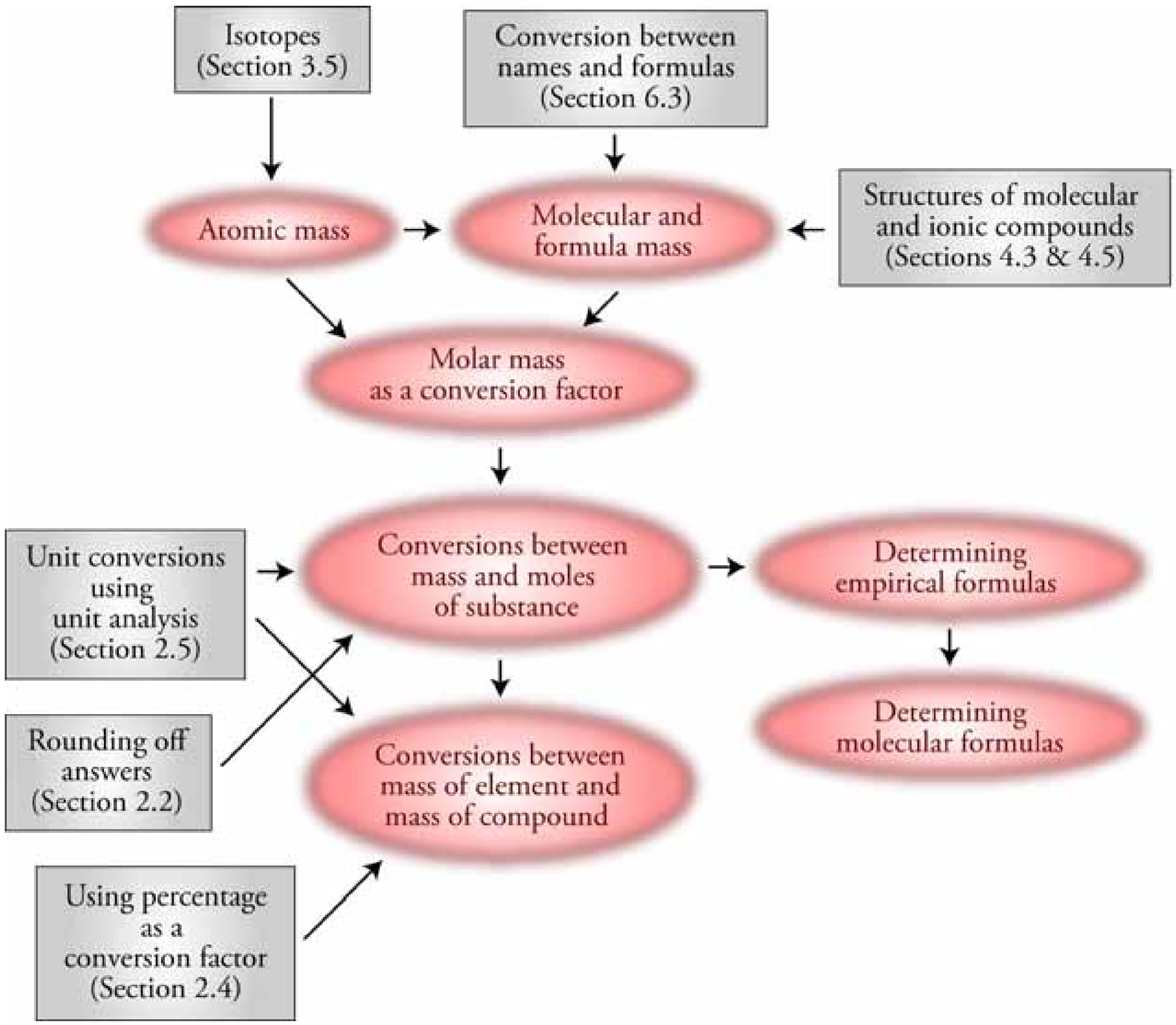
**Section 9.5 Determination of Empirical and Molecular Formulas**

*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 9 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*
- ☐ 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: 4, 5, 7, 10, and 12.)

- ☐ Reread the Study Sheets in this chapter and decide whether you will use them or some variation on them to complete the tasks they describe.
  - *Sample Study Sheet 9.1: Converting Between Mass of Element and Mass of Compound Containing the Element*
  - *Sample Study Sheet 9.2: Calculating Empirical Formulas*
  - *Sample Study Sheet 9.3: Calculating Molecular Formulas*
- ☐ 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: Molar Mass Conversion Factors*
*Internet: Percentage of an Element in a Compound*
*Internet: Combustion Analysis*
*Internet: Glossary Quiz*

## Exercises Key

✍ **Exercise 9.1 - Atomic Mass Calculations:** Gold is often sold in units of troy ounces. There are 31.10 grams per troy ounce. *(Objs 3 & 4)*

a. What is the atomic mass of gold?

**196.9665** (from periodic table)

b. What is the mass in grams of $6.022 \times 10^{23}$ gold atoms?

**196.9665 g** (There are $6.022 \times 10^{23}$ atoms per mole of atoms, and one mole of an element has a mass in grams equal to its atomic mass.)

c. Write the molar mass of gold as a conversion factor that can be used to convert between grams of gold and moles of gold.

$$\left(\frac{\mathbf{196.9665\ g\ Au}}{\mathbf{1\ mol\ Au}}\right)$$

d. What is the mass in grams of 0.20443 mole of gold?

$$?\ \text{g Au} = 0.20443\ \text{mol Au}\left(\frac{196.9665\ \text{g Au}}{1\ \text{mol Au}}\right) = \mathbf{40.266\ g\ Au}$$

e. What is the mass in milligrams of $7.046 \times 10^{-3}$ mole of gold?

$$?\ \text{mg Au} = 7.046 \times 10^{-3}\ \text{mol Au}\left(\frac{196.9665\ \text{g Au}}{1\ \text{mol Au}}\right)\left(\frac{10^3\ \text{mg}}{1\ \text{g}}\right) = \mathbf{1388\ mg\ Au}$$

f. How many moles of gold are in 1.00 troy ounce of pure gold?

$$? \text{ mol Au} = 1.00 \text{ troy oz Au}\left(\frac{31.10 \text{ g}}{1 \text{ troy oz}}\right)\left(\frac{1 \text{ mol Au}}{196.9665 \text{ g Au}}\right) = \mathbf{0.158 \text{ mol Au}}$$

**Exercise 9.2 - Molecular Mass Calculations:** A typical glass of wine contains about 16 g of ethanol, $C_2H_5OH$. *(Objs 5-7)*

a. What is the molecular mass of $C_2H_5OH$?

$$2(12.011) + 6(1.00794) + 1(15.9994) = \mathbf{46.069}$$

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 $C_2H_5OH$.

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

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

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

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.)

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

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

**Exercise 9.3 - Formula Mass Calculations:** A quarter teaspoon of a typical baking powder contains about 0.4 g of sodium hydrogen carbonate, $NaHCO_3$.

a. Calculate the formula mass of sodium hydrogen carbonate. *(Objs 10-12)*

$$\text{Formula Mass} = 1(22.9898) + 1(1.00794) + 1(12.011) + 3(15.9994)$$

$$= \mathbf{84.007}$$

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 $NaHCO_3$.

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

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

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

✍ **Exercise 9.4 - Molar Ratios of Element to Compound:** Find the requested conversion factors. *(Objs 13 & 14)*

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 9.5 - 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?

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

✍ **Exercise 9.6 - 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 15)*

$$?\ \text{kg V} = 2.3\ \text{kg}\ V_2O_5\left(\frac{10^3\ \text{g}}{1\ \text{kg}}\right)\left(\frac{1\ \text{mol}\ V_2O_5}{181.880\ \text{g}\ V_2O_5}\right)\left(\frac{2\ \text{mol V}}{1\ \text{mol}\ V_2O_5}\right)\left(\frac{50.9415\ \text{g V}}{1\ \text{mol V}}\right)\left(\frac{1\ \text{kg}}{10^3\ \text{g}}\right)$$

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

✍ **Exercise 9.7 – 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 16)*

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

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

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

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

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

✍ **Exercise 9.8 - 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 17)*

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

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

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

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

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

$$\cong 2\frac{1}{2} \text{ mol O} \times 2 = 5 \text{ mol O}$$

**Empirical Formula** $\mathbf{K_2S_2O_5}$

✍ **Exercise 9.9 – 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? *(Obj 19)*

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

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

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

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

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

## Review Questions Key

1. Complete each of the following conversion factors by filling in the blank on the top of the ratio.

   a. $\left(\frac{\mathbf{10^3}\text{ g}}{1\text{ kg}}\right)$  c. $\left(\frac{\mathbf{10^3}\text{ kg}}{1\text{ metric ton}}\right)$

   b. $\left(\frac{\mathbf{10^3}\text{ mg}}{1\text{ g}}\right)$  d. $\left(\frac{\mathbf{10^6}\ \mu\text{g}}{1\text{ g}}\right)$

2. Convert 3.45 × 10⁴ kg into grams.

$$? \text{ g} = 3.45 \times 10^4 \text{ kg}\left(\frac{10^3\text{ g}}{1\text{kg}}\right) = \mathbf{3.45 \times 10^7\ g}$$

3. Convert 184.570 g into kilograms.

$$? \text{ kg} = 184.570 \text{ g}\left(\frac{1\text{ kg}}{10^3\text{ g}}\right) = \mathbf{0.184570\ kg}$$

4. Convert 4.5000 × 10⁶ g into megagrams.

$$? \text{ Mg} = 4.5000 \times 10^6 \text{ g}\left(\frac{1\text{ kg}}{10^3\text{ g}}\right)\left(\frac{1\text{ Mg}}{10^3\text{ kg}}\right) = \mathbf{4.5000\ Mg}$$

5. Convert 871 Mg into grams.

$$? \text{ g} = 871 \text{ Mg}\left(\frac{10^3\text{ kg}}{1\text{ Mg}}\right)\left(\frac{10^3\text{ g}}{1\text{ kg}}\right) = \mathbf{8.71 \times 10^8\ g}$$

6. Surinam bauxite is an ore that is 54-57% aluminum oxide, $Al_2O_3$. What is the mass (in kilograms) of $Al_2O_3$ in 1256 kg of Surinam bauxite that is 55.3% $Al_2O_3$?

$$? \text{ kg } Al_2O_3 = 1256 \text{ kg Surinam bauxite}\left(\frac{55.3\text{ kg } Al_2O_3}{100\text{ kg Surinam bauxite}}\right) = \mathbf{695\ kg\ Al_2O_3}$$

## Key Ideas Answers

7. Because of the size and number of carbon atoms in any normal sample of carbon, it is **impossible** to count the atoms directly.
9. The atomic mass of any element is the **weighted** average of the masses of the **naturally** occurring isotopes of the element.
11. The number of grams in the molar mass of an element is the same as the element's **atomic mass**.
13. 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.

15. Formula mass is the weighted average of the masses of the naturally occurring **formula units** of the substance.
17. 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.
19. The subscripts in a molecular formula are always **whole-number** multiples of the subscripts in the empirical formula.

## Problems Key

### Section 9.2 Relating Mass to Numbers of Particles

21. What is the weighted average mass in atomic mass units (u) of each atom of the following elements?

    The atomic mass for each element in the periodic table tells you the weighted average mass in atomic mass units (u) of each atom of that element.

    a. sodium **22.9898 u** b. oxygen **15.9994 u**

23. What is the weighted average mass in grams of $6.022 \times 10^{23}$ atoms of the following elements?

    The atomic mass for each element in the periodic table tells you the mass, in grams, of $6.022 \times 10^{23}$ atoms of that element.

    a. sulfur **32.066 g** b. fluorine **18.9984 g**

25. What is the molar mass for each of the following elements?

    The atomic mass for each element in the periodic table tells you the molar mass, in grams per mole, of that element.

    a. zinc **65.39 g/mol** b. aluminum **26.9815 g/mol**

27. For each of the following elements, write a conversion factor that converts between mass in grams and moles of the substance. *(Obj 3)*

    a. iron $\left(\frac{55.845 \text{ g Fe}}{1 \text{ mol Fe}}\right)$

    b. krypton $\left(\frac{83.80 \text{ g Kr}}{1 \text{ mol Kr}}\right)$

29. A vitamin supplement contains 50 micrograms of the element selenium in each tablet. How many moles of selenium does each tablet contain? *(Obj 4)*

$$? \text{ mol Se} = 50 \text{ } \mu\text{g Se}\left(\frac{1 \text{ g}}{10^6 \text{ } \mu\text{g}}\right)\left(\frac{1 \text{ mol Se}}{78.96 \text{ g Se}}\right) = \mathbf{6.3 \times 10^{-7} \text{ mol Se}}$$

31. A multivitamin tablet contains $1.6 \times 10^{-4}$ mole of iron per tablet. How many milligrams of iron does each tablet contain? *(Obj 4)*

$$? \text{ mg Fe} = 1.6 \times 10^{-4} \text{ mol Fe}\left(\frac{55.845 \text{ g Fe}}{1 \text{ mol Fe}}\right)\left(\frac{10^3 \text{ mg}}{1 \text{ g}}\right) = \mathbf{8.9 \text{ mg Fe}}$$

## Section 9.3 Molar Mass and Chemical Compounds

33. 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 5 & 6)*

a. $H_3PO_2$

$$\text{molecular mass } H_3PO_2 = 3(1.00794) + 1(30.9738) + 2(15.9994)$$
$$= 65.9964 \text{ leads to } \left(\frac{65.9964 \text{ g } H_3PO_2}{1 \text{ mol } H_3PO_2}\right)$$

b. $C_6H_5NH_2$

$$\text{molecular mass } C_6H_5NH_2 = 6(12.011) + 7(1.00794) + 1(14.0067)$$
$$= 93.128 \text{ leads to } \left(\frac{93.128 \text{ g } C_6H_5NH_2}{1 \text{ mol } C_6H_5NH_2}\right)$$

35. 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 7)*

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?

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

38. For each of the following examples, decide whether it would be better to use the term *molecule* or *formula unit*. *(Obj 9)*

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**

40. 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 10 & 11)*

a. $BiBr_3$

$$\text{formula mass } BiBr_3 = 1(208.9804) + 3(79.904)$$
$$= 448.69 \text{ leads to } \left(\frac{448.69 \text{ g } BiBr_3}{1 \text{ mol } BiBr_3}\right)$$

b. $Al_2(SO_4)_3$

$$\text{formula mass } Al_2(SO_4)_3 = 2(26.9815) + 3(32.066) + 12(15.9994)$$
$$= 342.154 \text{ leads to } \left(\frac{342.154 \text{ g } Al_2(SO_4)_3}{1 \text{ mol } Al_2(SO_4)_3}\right)$$

42. A common antacid tablet contains 500 mg of calcium carbonate, $CaCO_3$. *(Obj 12)*

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?

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

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

44. 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 12)*

$$? \text{ mol } Al_2O_3 = 0.78 \text{ carat } Al_2O_3 \left(\frac{1 \text{ g}}{5 \text{ carats}}\right)\left(\frac{1 \text{ mol } Al_2O_3}{101.9612 \text{ g } Al_2O_3}\right)$$

$$= \mathbf{1.5 \times 10^{-3} \text{ mol } Al_2O_3}$$

### Section 9.4 Relationships Between Masses of Elements and Compounds

46. Write a conversion factor that converts between moles of nitrogen in nitrogen pentoxide, $N_2O_5$, and moles of $N_2O_5$. *(Obj 13)*

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

48. 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 $Cr_2O_3$. *(Objs 13 & 14)*

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

50. 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 14)*

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

52. A nutritional supplement contains 0.405 g of $CaCO_3$. The recommended daily value of calcium is 1.000 g Ca. *(Objs 13 & 15)*

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

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

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?

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

54. 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 15)*

$$? \mu\text{g } NaVO_3 = 10 \text{ } \mu\text{g V}\left(\frac{1 \text{ g}}{10^6 \text{ } \mu\text{g}}\right)\left(\frac{1 \text{ mol V}}{50.9415 \text{ g V}}\right)\left(\frac{1 \text{ mol } NaVO_3}{1 \text{ mol V}}\right)\left(\frac{121.9295 \text{ g } NaVO_3}{1 \text{ mol } NaVO_3}\right)\left(\frac{10^6 \text{ } \mu\text{g}}{1 \text{ g}}\right)$$

**= 24 µg $NaVO_3$**

56. 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 15)*

$$? \text{ kg Ti} = 0.401 \text{ Mg } TiCl_4 \left(\frac{10^6 \text{ g}}{1 \text{ Mg}}\right)\left(\frac{1 \text{ mol } TiCl_4}{189.678 \text{ g } TiCl_4}\right)\left(\frac{1 \text{ mol Ti}}{1 \text{ mol } TiCl_4}\right)\left(\frac{47.867 \text{ g Ti}}{1 \text{ mol Ti}}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right)$$

**= 101 kg Ti**

### Section 9.5 Determination of Empirical and Molecular Formulas

59. 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 16)*

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

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

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

61. 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 16)*

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

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

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

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

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

$$\cong 3\frac{1}{2} \text{ mol O} \times 2 = 7 \text{ mol O}$$

**Empirical Formula $Ca_2P_2O_7$**

63. 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 17)*

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

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

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

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

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

$$\cong 4 \text{ mol O} \times 2 = 8 \text{ mol O}$$

**Empirical Formula $Ni_3As_2O_8$**

65. 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 17)*

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

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

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

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

67. 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 17)*

$$\text{Molecular Formula} = (\text{Empirical Formula})_n$$

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

Molecular Formula = $(CNH_4)_2$ or $\mathbf{C_2N_2H_8}$

69. 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? *(Obj 18)*

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

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

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

Empirical Formula CHCl

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

Molecular Formula = $(CHCl)_6$ or $\mathbf{C_6H_6Cl_6}$

71. 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? *(Obj 18)*

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

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

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

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

73. 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?

$$\text{weighted average} = 0.07(2.65\text{ g}) + 0.04(2.75\text{ g}) + 0.89(2.90\text{ g}) = \mathbf{2.88\text{ g}}$$

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

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

75. 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.)

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

$$= \mathbf{4.515\text{ mol }Al_2O_3}$$

77. 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?

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

$$= \mathbf{1.1 \times 10^2\text{ mol Be}}$$

79. 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.)

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

81. 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?

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

**= 0.08720 kg $C_6H_5OH$**

83. 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 $Be_3Al_2(SiO_3)_6$?

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

**= 50.60 kg Be**

85. 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 $MoSi_2$**

87. 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 $KHC_2O_4$**

89. 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 $Na_2S_2O_5$**

91. 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.)

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

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

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

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

**Empirical Formula $MnH_4P_2O_8$ or $Mn(H_2PO_4)_2$ manganese(II) dihydrogen phosphate**

93. 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

95. 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 $1.347 \times 10^4$ kg of natural calamine that is 67.5% ZnO?

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

$$= \mathbf{7.30 \times 10^3 \text{ kg Zn}}$$

97. 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% $As_2O_3$?

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

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

99. 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 $1.0 \times 10^5$ kL of seawater?

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

**= $1.3 \times 10^2$ 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?

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

**= $2.9 \times 10^2$ t ore**

101. 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% $CaF_2$?

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

**= 6.8 t ore**

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

$$? \text{ g baking powder} = 1.0 \text{ mol NaHCO}_3\left(\frac{84.007 \text{ g NaHCO}_3}{1 \text{ mol NaHCO}_3}\right)\left(\frac{100 \text{ g baking powder}}{36 \text{ g NaHCO}_3}\right)$$

**= $2.3 \times 10^2$ g baking powder**

105. 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% $HfO_2$?

$$? \text{ t sand} = 120.5 \text{ kg Hf}\left(\frac{10^3 \text{ g}}{1 \text{ kg}}\right)\left(\frac{1 \text{ mol Hf}}{178.49 \text{ g Hf}}\right)\left(\frac{1 \text{ mol HfO}_2}{1 \text{ mol Hf}}\right)\left(\frac{210.49 \text{ g HfO}_2}{1 \text{ mol HfO}_2}\right)\left(\frac{1 \text{ kg}}{10^3 \text{ g}}\right)\left(\frac{100 \text{ kg sand}}{1.3 \text{ kg HfO}_2}\right)\left(\frac{1 \text{ t}}{10^3 \text{ kg}}\right)$$

**= 11 t zircon sand**