For Review

Chapter 3 Review Questions

Key Terms

chemical stoichiometry

Section 3.1
mass spectrometer
average atomic mass

Section 3.2
mole
Avogadro's number

Section 3.3
molar mass

Section 3.4
mass percent

Section 3.5
empirical formula
molecular formula

Section 3.6
chemical equation
reactants
products
balancing a chemical equation

Section 3.8
mole ratio

Section 3.9
stoichiometric quantities
Haber process
limiting reactant (reagent)
theoretical yield
percent yield

Summary

Stoichiometry deals with the quantities of materials consumed and produced in chemical reactions. It is, in effect, chemical arithmetic. The average atomic mass for each element is obtained by computing the average of the masses of the naturally occurring isotopes. All atomic masses are based on a mass scale that assigns exactly 12 atomic mass units to a ^{12}C atom.

A mole is a unit of measure equal to the number of carbon atoms in exactly 12 grams of pure ^{12}C. This number has been determined experimentally to be 6.02214×10^{23}, which is called Avogadro's number. One mole of any substance contains Avogadro's number of units. One mole of an element has a mass equal to the element's atomic mass in grams.

The molar mass (molecular weight) of a compound is the mass in grams of one mole of the compound and is computed by summing the average masses of its constituent atoms.

Percent composition represents the mass percent of each element in a compound:

$$\text{Mass percent} = \frac{\text{mass of element in 1 mole of substance}}{\text{mass of 1 mole of substance}} \times 100\%$$

The empirical formula is the simplest whole-number ratio of the various types of atoms in a compound and can be derived from the percent composition of the compound. The molecular formula is the exact formula of a molecule of a substance and is always an integer multiple of the empirical formula.

In a chemical reaction, atoms are neither created nor destroyed; they are merely reorganized. All atoms present in the reactants must be accounted for among the products. A chemical equation represents the chemical reaction showing reactants on the left side of an arrow and products on the right. A balanced equation gives the relative numbers of reactant and product molecules.

Amounts of reactants consumed and products formed can be calculated from the balanced equation for a reaction by using the mole ratios relating the reactants and products. The limiting reactant (reagent) is the one that is consumed first and thus determines how much product can be formed.

The theoretical yield of a product is the maximum amount that can be produced from a given amount of the limiting reactant. The actual yield, the amount of product actually obtained in a given experiment, is always less than the theoretical yield. The actual yield is usually represented as a percent yield: the percentage of the theoretical yield actually obtained.

In-Class Discussion Questions

These questions are designed to be considered by groups of students in class. Often these questions work well for introducing a particular topic in class.

1. The following are actual student responses to the question: Why is it necessary to balance chemical equations?

   a. The chemicals will not react until you have added the correct mole ratios.
   b. The correct products will not be formed unless the right amount of reactants have been added.
   c. A certain number of products cannot be formed without a certain number of reactants.
   d. The balanced equation tells you how much reactant you need and allows you to predict how much product you'll make.

e. A mole-to-mole ratio must be established for the reaction to occur as written.

Justify the best choice, and for choices you did not pick, explain what is wrong with them.

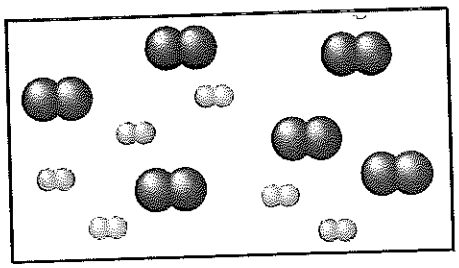
2. What information do we get from a formula? From an equation?

3. You are making cookies and are missing a key ingredient—eggs. You have most of the other ingredients needed to make the cookies, except you have only 1.33 cups of butter and no eggs. You note that the recipe calls for 2 cups of butter and 3 eggs (plus the other ingredients) to make 6 dozen cookies. You call a friend and have him bring you some eggs.
   a. How many eggs do you need?
   b. If you use all the butter (and get enough eggs), how many cookies will you make?

   Unfortunately, your friend hangs up before you tell him how many eggs you need. When he arrives, he has a surprise for you—to save time, he has broken them all in a bowl for you. You ask him how many he brought, and he replies, "I can't remember." You weigh the eggs and find that they weigh 62.1 g. Assuming that an average egg weighs 34.21 g,
   a. How much butter is needed to react with all the eggs?
   b. How many cookies can you make?
   c. Which will you have left over, eggs or butter?
   d. How much is left over?

4. Nitrogen (N_2) and hydrogen (H_2) react to form ammonia (NH_3).

   Consider the mixture of N_2 ( ) and H_2 ( ) in a closed container as illustrated below:



   Assuming the reaction goes to completion, draw a representation of the product mixture. Explain how you arrived at this representation.

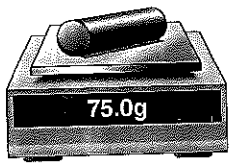
5. For the preceding question, which of the following equations best represents the reaction?
   a. $6N_2 + 6H_2 \longrightarrow 4NH_3 + 4N_2$
   b. $N_2 + H_2 \longrightarrow NH_3$
   c. $N + 3H \longrightarrow NH_3$
   d. $N_2 + 3H_2 \longrightarrow 2NH_3$
   e. $2N_2 + 6H_2 \longrightarrow 4NH_3$

   Justify your choice, and for choices you did not pick, explain what is wrong with them.

6. You know that chemical *A* reacts with chemical *B*. You react 10.0 g *A* with 10.0 g *B*. What information do you need to determine the amount of product that will be produced? Explain.

7. A new grill has a mass of 30.0 kg. You put 3.0 kg of charcoal in the grill. You burn all the charcoal and the grill has a mass of 30.0 kg. What is the mass of the gases given off? Explain.

8. Consider an iron bar on a balance as shown.



   As the iron bar rusts, which of the following is true? Explain your answer.
   a. The balance will read less than 75.0 g.
   b. The balance will read 75.0 g.
   c. The balance will read greater than 75.0 g.
   d. The balance will read greater than 75.0 g, but if the bar is removed, the rust is scraped off, and the bar replaced, the balance will read 75.0 g.

9. You may have noticed that water sometimes drips from the exhaust of a car as it is running. Is this evidence that there is at least a small amount of water originally present in the gasoline? Explain.

Questions 10 and 11 deal with the following situation: You react chemical *A* with chemical *B* to make one product. It takes 100 g of *A* to react completely with 20 g *B*.

10. What is the mass of the product?
    a. Less than 10 g
    b. Between 20 and 100 g
    c. Between 100 and 120 g
    d. Exactly 120 g
    e. More than 120 g

11. What is true about the chemical properties of the product?
    a. The properties are more like chemical *A*.
    b. The properties are more like chemical *B*.
    c. The properties are an average of those of chemical *A* and chemical *B*.
    d. The properties are not necessarily like either chemical *A* or chemical *B*.
    e. The properties are more like chemical *A* or more like chemical *B*, but more information is needed.

    Justify your choice, and for choices you did not pick, explain what is wrong with them.

12. Is there a difference between a homogeneous mixture of hydrogen and oxygen in a 2:1 mole ratio and a sample of water vapor? Explain.

13. Chlorine exists mainly as two isotopes, ^{37}Cl and ^{35}Cl. Which is more abundant? How do you know?

14. The average mass of a carbon atom is 12.011. Assuming you could pick up one carbon atom, estimate the chance that you would randomly get one with a mass of 12.011. Support your answer.

15. Can the subscripts in a chemical formula be fractions? Explain. Can the coefficients in a balanced chemical equation be fractions? Explain. Changing the subscripts of chemicals can balance the equations mathematically. Why is this unacceptable?
16. Consider the equation $2A + B \longrightarrow A_2B$. If you mix 1.0 mol of A with 1.0 mol of B, how many moles of A_2B can be produced?
17. According to the law of conservation of mass, mass cannot be gained or destroyed in a chemical reaction. Why can't you simply add the masses of two reactants to determine the total mass of product?

A blue question or exercise number indicates that the answer to that question or exercise appears at the back of the book and a solution appears in the *Solutions Guide*.

Questions

18. The atomic mass of boron (B) is given in the periodic table as 10.81, yet no single atom of boron has a mass of 10.81 amu. Explain.
19. What is the difference between the empirical and molecular formulas of a compound? Can they ever be the same? Explain.
20. Why is the actual yield of a reaction often less than the theoretical yield?

Exercises

In this section similar exercises are paired.

Atomic Masses and the Mass Spectrometer

21. The element magnesium (Mg) has three stable isotopes with the following masses and abundances:

Isotope	Mass (amu)	Abundance
^{24}Mg	23.9850	78.99%
^{25}Mg	24.9858	10.00%
^{26}Mg	25.9826	11.01%

Calculate the average atomic mass (the atomic weight) of magnesium from these data.

22. An element consists of 1.40% of an isotope with mass 203.973 amu, 24.10% of an isotope with mass 205.9745 amu, 22.10% of an isotope with mass 206.9759 amu, and 52.40% of an isotope with mass 207.9766 amu. Calculate the average atomic mass and identify the element.
23. The element europium exists in nature as two isotopes: ^{151}Eu has a mass of 150.9196 amu, and ^{153}Eu has a mass of 152.9209 amu. The average atomic mass of europium is 151.96 amu. Calculate the relative abundance of the two europium isotopes.
24. The element rhenium (Re) has two naturally occurring isotopes, ^{185}Re and ^{187}Re, with an average atomic mass of 186.207 amu. Rhenium is 62.60% ^{187}Re, and the atomic mass of ^{187}Re is 186.956 amu. Calculate the mass of ^{185}Re.
25. The mass spectrum of bromine (Br_2) consists of three peaks with the following characteristics:

Mass (amu)	Relative Size
157.84	0.2534
159.84	0.5000
161.84	0.2466

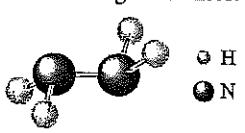
How do you interpret these data?

26. Gallium arsenide, GaAs, has gained widespread use in semiconductor devices that convert light and electrical signals in fiber-optic communications systems. Gallium consists of 60.% ^{69}Ga and 40.% ^{71}Ga. Arsenic has only one naturally occurring isotope, ^{75}As. Gallium arsenide is a polymeric material, but its mass spectrum shows fragments with the formulas GaAs and Ga_2As_2. What would the distribution of peaks look like for these two fragments?

Moles and Molar Masses

27. Calculate the mass of 500. atoms of iron (Fe).
28. How many Fe atoms and how many moles of Fe atoms are in 500.0 g of iron?
29. Diamond is a natural form of pure carbon. How many atoms of carbon are in a 1.00-carat diamond (1.00 carat = 0.200 g)?
30. A diamond contains 5.0×10^{21} atoms of carbon. How many moles of carbon and how many grams of carbon are in this diamond?
31. Aluminum metal is produced by passing an electric current through a solution of aluminum oxide (Al_2O_3) dissolved in molten cryolite (Na_3AlF_6). Calculate the molar masses of Al_2O_3 and Na_3AlF_6.
32. The Freons are a class of compounds containing carbon, chlorine, and fluorine. While they have many valuable uses, they have been shown to be responsible for depletion of the ozone in the upper atmosphere. In 1991, two replacement compounds for Freons went into production: HFC-134a (CH_2FCF_3) and HCFC-124 ($CHClFCF_3$). Calculate the molar masses of these two compounds.
33. Calculate the molar mass of the following substances.

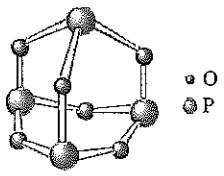
a. 

b. 

c. $(NH_4)_2Cr_2O_7$

34. Calculate the molar mass of the following substances.

a.



b. $Ca_3(PO_4)_2$ **c.** Na_2HPO_4

35. How many moles of compound are present in 1.00 g of each of the compounds in Exercise 33?

36. How many moles of compound are present in 1.00 g of each of the compounds in Exercise 34?

37. How many grams of compound are present in 5.00 mol of each of the compounds in Exercise 33?

38. How many grams of compound are present in 5.00 mol of each of the compounds in Exercise 34?

39. How many grams of nitrogen are present in 5.00 mol of each of the compounds in Exercise 33?

40. How many grams of phosphorus are present in 5.00 mol of each of the compounds in Exercise 34?

41. How many molecules (or formula units) are present in 1.00 g of each of the compounds in Exercise 33?

42. How many molecules (or formula units) are present in 1.00 g of each of the compounds in Exercise 34?

43. How many atoms of nitrogen are present in 1.00 g of each of the compounds in Exercise 33?

44. How many atoms of phosphorus are present in 1.00 g of each of the compounds in Exercise 34?

45. Ascorbic acid, or vitamin C ($C_6H_8O_6$), is an essential vitamin. It cannot be stored by the body and must be present in the diet. What is the molar mass of ascorbic acid? Vitamin C tablets are taken as a dietary supplement. If a typical tablet contains 500.0 mg of vitamin C, how many moles and how many molecules of vitamin C does it contain?

46. The molecular formula of acetylsalicylic acid (aspirin), one of the most commonly used pain relievers, is $C_9H_8O_4$.

a. Calculate the molar mass of aspirin.

b. A typical aspirin tablet contains 500. mg of $C_9H_8O_4$. How many moles of $C_9H_8O_4$ molecules and how many molecules of acetylsalicylic acid are in a 500.-mg tablet?

47. How many moles are represented by each of these samples?

a. 2.49×10^{20} molecules of carbon monoxide

b. 15.0 g of copper(II) sulfate

c. 100 molecules (exactly) of sulfuric acid

d. 6.210 mg of potassium oxide

48. How many moles are represented by each of these samples?

a. 150.0 g Fe_2O_3 **c.** 1.5×10^{16} molecules of BF_3

b. 10.0 mg NO_2

49. Calculate the mass in grams of the following:

a. 1.27 mmol of carbon dioxide

b. 2.00×10^{22} molecules of nitrogen trichloride

c. 0.00451 mol of ammonium carbonate

d. a single nitrogen (N_2) molecule

e. 62.7 mol of copper(II) sulfate

50. How many atoms of nitrogen are present in 5.00 g of each of the following?

a. glycine, $C_2H_5O_2N$ **c.** calcium nitrate

b. magnesium nitride **d.** dinitrogen tetroxide

51. Aspartame is an artificial sweetener that is 160 times sweeter than sucrose (table sugar) when dissolved in water. It is marketed as Nutra-Sweet. The molecular formula of aspartame is $C_{14}H_{18}N_2O_5$.

a. Calculate the molar mass of aspartame.

b. How many moles of molecules are present in 10.0 g aspartame?

c. Calculate the mass in grams of 1.56 mol aspartame.

d. How many molecules are in 5.0 mg aspartame?

e. How many atoms of nitrogen are in 1.2 g aspartame?

f. What is the mass in grams of 1.0×10^9 molecules of aspartame?

g. What is the mass in grams of one molecule of aspartame?

52. Chloral hydrate ($C_2H_3Cl_3O_2$) is a drug formerly used as a sedative and hypnotic. It is the compound used to make "Mickey Finns" in detective stories.

a. Calculate the molar mass of chloral hydrate.

b. How many moles of $C_2H_3Cl_3O_2$ molecules are in 500.0 g chloral hydrate?

c. What is the mass in grams of 2.0×10^{-2} mol chloral hydrate?

d. How many chlorine atoms are in 5.0 g chloral hydrate?

e. What mass of chloral hydrate would contain 1.0 g Cl?

f. What is the mass of exactly 500 molecules of chloral hydrate?

Percent Composition

53. In 1987 the first substance to act as a superconductor at a temperature above that of liquid nitrogen (77 K) was discovered. The approximate formula of this substance is $YBa_2Cu_3O_7$. Calculate the percent composition by mass of this material.

54. Calculate the percent composition by mass of the following compounds that are important starting materials for synthetic polymers:

a. $C_3H_4O_2$ (acrylic acid, from which acrylic plastics are made)

b. $C_4H_6O_2$ (methyl acrylate, from which Plexiglas is made)

c. C_3H_3N (acrylonitrile, from which Orlon is made)

55. Several important compounds contain only nitrogen and oxygen. Place the following compounds in order of increasing mass percent of nitrogen.

a. NO, a gas formed by the reaction of N_2 with O_2 in internal combustion engines

b. NO_2, a brown gas mainly responsible for the brownish color of photochemical smog

c. N_2O_4, a colorless liquid used as fuel in space shuttles
d. N_2O, a colorless gas sometimes used as an anesthetic by dentists (known as laughing gas)

56. Arrange the following substances in order of increasing mass percent of carbon.
a. caffeine, $C_8H_{10}N_4O_2$
b. sucrose, $C_{12}H_{22}O_{11}$
c. ethanol, C_2H_5OH

57. Vitamin B_{12}, cyanocobalamin, is essential for human nutrition. It is concentrated in animal tissue but not in higher plants. Although nutritional requirements for the vitamin are quite low, people who abstain completely from animal products may develop a deficiency anemia. Cyanocobalamin is the form used in vitamin supplements. It contains 4.34% cobalt by mass. Calculate the molar mass of cyanocobalamin, assuming that there is one atom of cobalt in every molecule of cyanocobalamin.

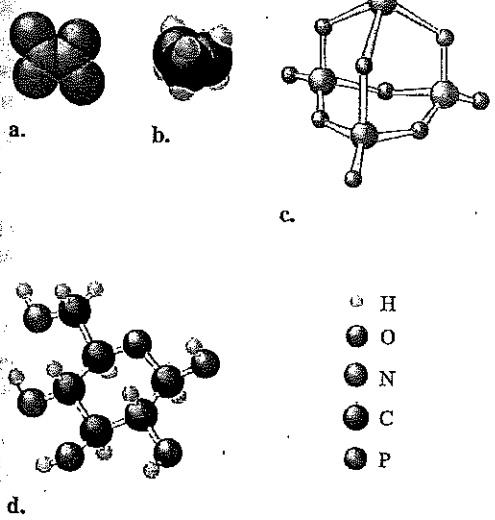
58. Fungal laccase, a blue protein found in wood-rotting fungi, is 0.390% Cu by mass. If a fungal laccase molecule contains 4 copper atoms, what is the molar mass of fungal laccase?

Empirical and Molecular Formulas

59. Express the composition of each of the following compounds as the mass percents of its elements.
a. formaldehyde, CH_2O
b. glucose, $C_6H_{12}O_6$
c. acetic acid, $HC_2H_3O_2$

60. Considering your answer to Exercise 59, which type of formula, empirical or molecular, can be obtained from elemental analysis that gives percent composition?

61. Give the empirical formula for each of the compounds represented below.



62. Determine the molecular formulas to which the following empirical formulas and molar masses pertain.
a. SNH (188.35 g/mol)
b. $NPCl_2$ (347.64 g/mol)
c. CoC_4O_4 (341.94 g/mol)
d. SN (184.32 g/mol)

63. One of the most commonly used white pigments in paint is a compound of titanium and oxygen that contains 59.9% Ti by mass. Determine the empirical formula of this compound.

64. The compound adrenaline contains 56.79% C, 6.56% H, 28.37% O, and 8.28% N by mass. What is the empirical formula for adrenaline?

65. There are two binary compounds of mercury and oxygen. Heating either of them results in the decomposition of the compound, with oxygen gas escaping into the atmosphere while leaving a residue of pure mercury. Heating 0.6498 g of one of the compounds leaves a residue of 0.6018 g. Heating 0.4172 g of the other compound results in a mass loss of 0.016 g. Determine the empirical formula of each compound.

66. A sample of urea contains 1.121 g N, 0.161 g H, 0.480 g C, and 0.640 g O. What is the empirical formula of urea?

67. A compound that contains only nitrogen and oxygen is 30.4% N by mass; the molar mass of the compound is 92 g/mol. What is the empirical formula of the compound? What is the molecular formula of the compound?

68. A compound containing only sulfur and nitrogen is 69.6% S by mass; the molar mass is 184 g/mol. What are the empirical and molecular formulas of the compound?

69. Adipic acid is an organic compound composed of 49.31% C, 43.79% O, and the rest hydrogen. If the molar mass of adipic acid is 146.1 g/mol, what are the empirical and molecular formulas for adipic acid?

70. Maleic acid is an organic compound composed of 41.39% C, 3.47% H, and the rest oxygen. If 0.129 mol of maleic acid has a mass of 15.0 g, what are the empirical and molecular formulas of maleic acid?

71. Many homes in rural America are heated by propane gas, a compound that contains only carbon and hydrogen. Complete combustion of a sample of propane produced 2.641 g of carbon dioxide and 1.442 g of water as the only products. Find the empirical formula of propane.

72. A compound contains only C, H, and N. Combustion of 35.0 mg of the compound produces 33.5 mg CO_2 and 41.1 mg H_2O. What is the empirical formula of the compound?

73. Cumene is a compound containing only carbon and hydrogen that is used in the production of acetone and phenol in the chemical industry. Combustion of 47.6 mg cumene produces some CO_2 and 42.8 mg water. The molar mass of cumene is between 115 and 125 g/mol. Determine the empirical and molecular formulas.

74. A compound contains only carbon, hydrogen, and oxygen. Combustion of 10.68 mg of the compound yields 16.01 mg CO_2 and 4.37 mg H_2O. The molar mass of the compound is 176.1 g/mol. What are the empirical and molecular formulas of the compound?

Balancing Chemical Equations

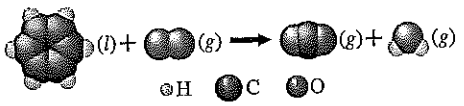
75. Write a balanced chemical equation that describes each of the following.
   a. Iron metal reacts with oxygen to form rust, iron(III) oxide.
   b. Calcium metal reacts with water to produce aqueous calcium hydroxide and hydrogen gas.
   c. Aqueous barium hydroxide reacts with aqueous sulfuric acid to produce solid barium sulfate and water.

76. Give the balanced equation for each of the following chemical reactions:
   a. Glucose ($C_6H_{12}O_6$) reacts with oxygen gas to produce gaseous carbon dioxide and water vapor.
   b. Solid iron(III) sulfide reacts with gaseous hydrogen chloride to form solid iron(III) chloride and hydrogen sulfide gas.
   c. Carbon disulfide liquid reacts with ammonia gas to produce hydrogen sulfide gas and solid ammonium thiocyanate (NH_4SCN).

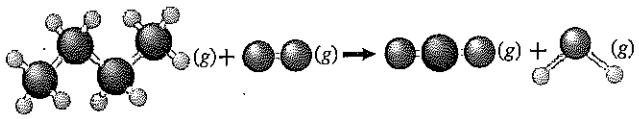
77. Balance the following equations:
   a. $Cu(s) + AgNO_3(aq) \rightarrow Ag(s) + Cu(NO_3)_2(aq)$
   b. $Zn(s) + HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$
   c. $Au_2S_3(s) + H_2(g) \rightarrow Au(s) + H_2S(g)$

78. Balance the following equations:
   a. $Ca(OH)_2(aq) + H_3PO_4(aq) \rightarrow H_2O(l) + Ca_3(PO_4)_2(s)$
   b. $Al(OH)_3(s) + HCl(aq) \rightarrow AlCl_3(aq) + H_2O(l)$
   c. $AgNO_3(aq) + H_2SO_4(aq) \rightarrow Ag_2SO_4(s) + HNO_3(aq)$

79. Balance the following equations representing combustion reactions:
   a.



   b.



   c. $C_{12}H_{22}O_{11}(s) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$
   d. $Fe(s) + O_2(g) \rightarrow Fe_2O_3(s)$
   e. $FeO(s) + O_2(g) \rightarrow Fe_2O_3(s)$

80. Balance the following equations:
   a. $Cr(s) + S_8(s) \rightarrow Cr_2S_3(s)$
   b. $NaHCO_3(s) \xrightarrow{\text{Heat}} Na_2CO_3(s) + CO_2(g) + H_2O(g)$
   c. $KClO_3(s) \xrightarrow{\text{Heat}} KCl(s) + O_2(g)$
   d. $Eu(s) + HF(g) \rightarrow EuF_3(s) + H_2(g)$

81. Silicon is produced for the chemical and electronics industries by the following reactions. Give the balanced equation for each reaction.
   a. $SiO_2(s) + C(s) \xrightarrow[\text{arc furnace}]{\text{Electric}} Si(s) + CO(g)$
   b. Silicon tetrachloride is reacted with very pure magnesium, producing silicon and magnesium chloride.
   c. $Na_2SiF_6(s) + Na(s) \rightarrow Si(s) + NaF(s)$

82. Phosphorus occurs naturally in the form of fluorapatite, $CaF_2 \cdot 3Ca_3(PO_4)_2$, the dot indicating 1 part CaF_2 to 3 parts $Ca_3(PO_4)_2$. This mineral is reacted with an aqueous solution of sulfuric acid in the preparation of a fertilizer. The products are phosphoric acid, hydrogen fluoride, and gypsum, $CaSO_4 \cdot 2H_2O$. Write and balance the chemical equation describing this process.

83. The sugar sucrose, which is present in many fruits and vegetables, reacts in the presence of certain yeast enzymes to produce ethyl alcohol (ethanol) and carbon dioxide gas. Balance the following equation for this reaction of sucrose.

$$C_{12}H_{22}O_{11}(aq) + H_2O(l) \rightarrow C_2H_5OH(aq) + CO_2(g)$$

84. Glass is a mixture of several compounds, but a major constituent of most glass is calcium silicate, $CaSiO_3$. Glass can be etched by treatment with hydrofluoric acid; HF attacks the calcium silicate of the glass, producing gaseous and water-soluble products (which can be removed by washing the glass). For example, the volumetric glassware in chemistry laboratories is often graduated by using this process. Balance the following equation for the reaction of hydrofluoric acid with calcium silicate.

$$CaSiO_3(s) + HF(aq) \rightarrow CaF_2(aq) + SiF_4(g) + H_2O(l)$$

Reaction Stoichiometry

85. Calculate the masses of Cr_2O_3, N_2, and H_2O produced from 10.8 g $(NH_4)_2Cr_2O_7$ in an ammonium dichromate volcano reaction as described in Sample Exercise 3.14.

86. Over the years, the thermite reaction has been used for welding railroad rails, in incendiary bombs, and to ignite solid-fuel rocket motors. The reaction is

$$Fe_2O_3(s) + 2Al(s) \longrightarrow 2Fe(l) + Al_2O_3(s)$$

What masses of iron(III) oxide and aluminum must be used to produce 15.0 g iron? What is the maximum mass of aluminum oxide that could be produced?

87. The reusable booster rockets of the U.S. space shuttle employ a mixture of aluminum and ammonium perchlorate for fuel. A possible equation for this reaction is

$$3Al(s) + 3NH_4ClO_4(s) \longrightarrow Al_2O_3(s) + AlCl_3(s) + 3NO(g) + 6H_2O(g)$$

What mass of NH_4ClO_4 should be used in the fuel mixture for every kilogram of Al?

88. One of relatively few reactions that takes place directly between two solids at room temperature is

$$Ba(OH)_2 \cdot 8H_2O(s) + NH_4SCN(s) \longrightarrow Ba(SCN)_2(s) + H_2O(l) + NH_3(g)$$

In this equation, the $\cdot 8H_2O$ in $Ba(OH)_2 \cdot 8H_2O$ indicates the presence of eight water molecules. This compound is called barium hydroxide octahydrate.

a. Balance the equation.

b. What mass of ammonium thiocyanate (NH_4SCN) must be used if it is to react completely with 6.5 g barium hydroxide octahydrate?

89. Coke is an impure form of carbon that is often used in the industrial production of metals from their oxides. If a sample of coke is 95% carbon by mass, determine the mass of coke needed to react completely with 1.0 ton of copper(II) oxide.

$$2CuO(s) + C(s) \longrightarrow 2Cu(s) + CO_2(g)$$

90. Bacterial digestion is an economical method of sewage treatment. The reaction

$$5CO_2(g) + 55NH_4^+(aq) + 76O_2(g) \xrightarrow{\text{bacteria}} \underset{\text{bacterial tissue}}{C_5H_7O_2N(s)} + 54NO_2^-(aq) + 52H_2O(l) + 109H^+(aq)$$

is an intermediate step in the conversion of the nitrogen in organic compounds into nitrate ions. How much bacterial tissue is produced in a treatment plant for every 1.0×10^4 kg of wastewater containing 3.0% NH_4^+ ions by mass? Assume that 95% of the ammonium ions are consumed by the bacteria.

91. The compound cisplatin, $Pt(NH_3)_2Cl_2$, has been studied extensively as an antitumor agent.

a. Calculate the elemental percent composition by mass of cisplatin.

b. Cisplatin is synthesized as follows:

$$K_2PtCl_4(aq) + 2NH_3(aq) \longrightarrow Pt(NH_3)_2Cl_2(s) + 2KCl(aq)$$

What mass of cisplatin can be made from 100. g of K_2PtCl_4 and sufficient NH_3? What mass of KCl is also produced?

92. Aspirin ($C_9H_8O_4$) is synthesized by reacting salicylic acid ($C_7H_6O_3$) with acetic anhydride ($C_4H_6O_3$). The balanced equation is

$$C_7H_6O_3 + C_4H_6O_3 \longrightarrow C_9H_8O_4 + HC_2H_3O_2$$

a. What mass of acetic anhydride is needed to completely consume 1.00×10^2 g salicylic acid?

b. What is the maximum mass of aspirin (the theoretical yield) that could be produced in this reaction?

Limiting Reactants and Percent Yield

93. Consider the reaction

$$Mg(s) + I_2(s) \longrightarrow MgI_2(s)$$

Identify the limiting reagent in each of the reaction mixtures below:

a. 100 atoms of Mg and 100 molecules of I_2
b. 150 atoms of Mg and 100 molecules of I_2
c. 200 atoms of Mg and 300 molecules of I_2
d. 0.16 mol Mg and 0.25 mol I_2
e. 0.14 mol Mg and 0.14 mol I_2
f. 0.12 mol Mg and 0.08 mol I_2
g. 6.078 g Mg and 63.46 g I_2
h. 1.00 g Mg and 2.00 g I_2
i. 1.00 g Mg and 20.00 g I_2

94. Consider the reaction

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$

Identify the limiting reagent in each of the reaction mixtures given below:

a. 50 molecules of H_2 and 25 molecules of O_2
b. 100 molecules of H_2 and 40 molecules of O_2
c. 100 molecules of H_2 and 100 molecules of O_2
d. 0.50 mol H_2 and 0.75 mol O_2
e. 0.80 mol H_2 and 0.75 mol O_2
f. 1.0 g H_2 and 0.25 mol O_2
g. 5.00 g H_2 and 56.00 g O_2

95. Mercury and bromine will react with each other to produce mercury(II) bromide:

$$Hg(l) + Br_2(l) \longrightarrow HgBr_2(s)$$

a. What mass of $HgBr_2$ can be produced from the reaction of 10.0 g Hg and 9.00 g Br_2? What mass of which reagent is left unreacted?

b. What mass of $HgBr_2$ can be produced from the reaction of 5.00 mL mercury (density = 13.6 g/mL) and 5.00 mL bromine (density = 3.10 g/mL)?

96. Hydrogen peroxide is used as a cleaning agent in the treatment of cuts and abrasions for several reasons. It is an oxidizing agent that can directly kill many microorganisms; it decomposes upon contact with blood, releasing elemental oxygen gas (which inhibits the growth of anaerobic microorganisms); and it foams upon contact with blood, which provides a cleansing action. In the laboratory, small quantities of hydrogen peroxide can be prepared by the action of an acid on an alkaline earth metal peroxide, such as barium peroxide:

$$BaO_2(s) + 2HCl(aq) \longrightarrow H_2O_2(aq) + BaCl_2(aq)$$

What amount of hydrogen peroxide should result when 1.50 g of barium peroxide is treated with 25.0 mL of hy-