Name:_____Class: _____ Date: _____

Skills Worksheet

Sample Problem Set

Teacher Notes and Answers

STOICHIOMETRY

1. 15.0 mol $(NH_4)_2SO_4$
2. a. 51 g Al
   b. 101 g Fe
   c. 1.83 mol Fe_2O_3
3. 0.303 g H_2
4. $H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2H_2O$; 1.11 g H_2SO_4
5. a. $H_3PO_4 + 2NH_3 \rightarrow (NH_4)_2HPO_4$
   b. 0.293 mol $(NH_4)_2HPO_4$
   c. 970 kg NH_3
6. a. 90.0 mol $ZnCO_3$; 60.0 mol $C_6H_8O_7$
   b. 13.5 kg H_2O; 33.0 kg CO_2
7. a. 60.9 g methyl butanoate
   b. 3261 g H_2O
8. a. 0.450 mol N_2
   b. 294 g NH_4NO_3
9. $Pb(NO_3)_2 + 2KI \rightarrow PbI_2 + 2KNO_3$; 0.751 mg KNO_3
10. 3.3 mol $PbSO_4$
11. $2LiOH + CO_2 \rightarrow H_2O + Li_2CO_3$; 360 g H_2O
12. a. 38.1 g H_2O
    b. 40.1 g H_3PO_4
    c. 0.392 mol H_2O
13. $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$; 81.0 g C_2H_5OH
14. 76.5 g H_2SO_4; 12.5 g O_2
15. $2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$; 1.31 g CO_2
16. a. $2N_2H_4 + N_2O_4 \rightarrow 3N_2 + 4H_2O$
    b. 1 mol N_2O_4 to 3 mol N_2
    c. 30 000 mol N_2
    d. 3.52×10^5 g H_2O
17. $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$; 1.1954 mol O_2
18. $2Fe + 3Cl_2 \rightarrow 2FeCl_3$; 30.5 g Fe
19. 9.26 mg CdS
20. a. 1.59 mol CO_2
    b. 0.0723 mol $C_3H_5(OH)_3$
    c. 535 g Mn_2O_3
    d. 8.33 g $C_3H_5(OH)_3$; 4.97 g CO_2
21. a. 3.29×10^3 kg of HCl
    b. 330 g CO_2 (s)
22. a. 6.53×10^5 g NH_4ClO_4
    b. 160 kg NO(g)
23. a. 1.70×10^6 mol H_3PO_4
    b. 666 kg of $CaSO_4 \cdot 2H_2O$
    c. 34 metric tons of H_3PO_4
24. 1670 kg

Name:_____Class: _____ Date: _____

Skills Worksheet

Sample Problem Set

Stoichiometry

So far in your chemistry course, you have learned that chemists count quantities of elements and compounds in terms of moles and that they relate moles of a substance to mass by using the molar mass. In addition, you have learned to write chemical equations so that they represent the rearrangements of atoms that take place during chemical reactions, and you have learned to balance these equations. In this chapter you will be able to put these separate skills together to accomplish one of the most important tasks of chemistry—using chemical equations to make predictions about the quantities of substances that react or are given off as products and relating those quantities to one another. This process of relating quantities of reactants and products in a chemical reaction to one another is called *stoichiometry*.

First, look at an analogy.

Suppose you need to make several sandwiches to take on a picnic with friends. You decide to make turkey-and-cheese sandwiches using the following "equation:"

2 bread slices + 2 turkey slices + 1 lettuce leaf + 1 cheese slice
$\rightarrow$ 1 turkey-and-cheese sandwich

This equation shows that you need those ingredients in a ratio of 2:2:1:1, respectively. You can use this equation to predict that you would need 30 turkey slices to make 15 sandwiches or 6 cheese slices to go with 12 turkey slices.

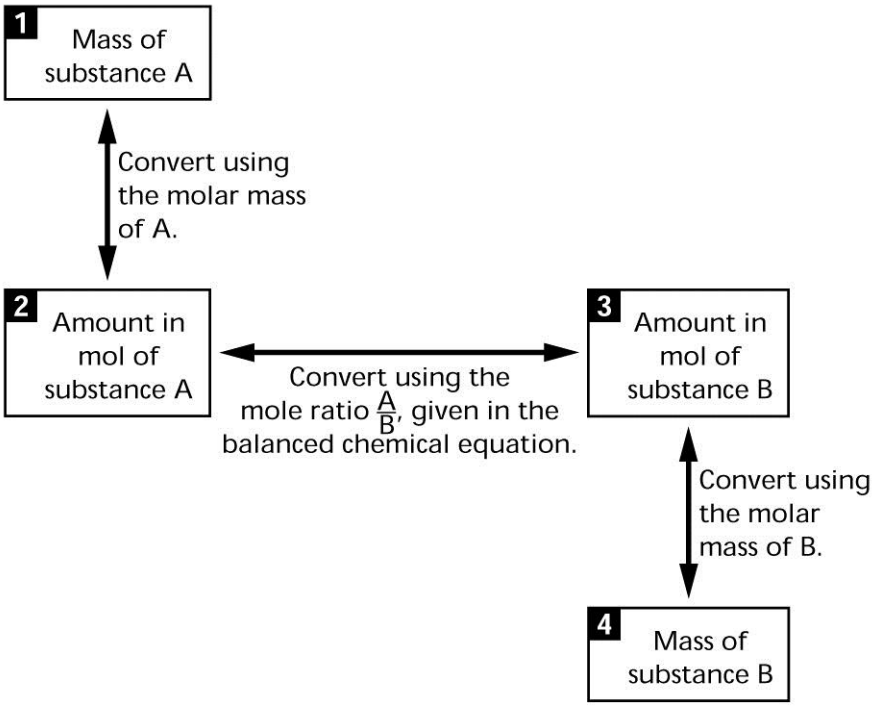
Zinc reacts with oxygen according to the following balanced chemical equation:

$$2Zn + O_2 \rightarrow 2ZnO$$

Like the sandwich recipe, this equation can be viewed as a "recipe" for zinc oxide. It tells you that reacting two zinc atoms with a molecule of oxygen will produce two formula units of zinc oxide. Can you predict how many zinc oxide units could be formed from 500 zinc atoms? Could you determine how many moles of oxygen molecules it would take to react with 4 mol of zinc atoms? What if you had 22 g of zinc and wanted to know how many grams of ZnO could be made from it? Keep in mind that the chemical equation relates amounts, not masses, of products and reactants. The problems in this chapter will show you how to solve problems of this kind.

Sample Problem Set *continued*

General Plan for Solving Stoichiometry Problems



Sample Problem 1

Ammonia is made industrially by reacting nitrogen and hydrogen under pressure, at high temperature, and in the presence of a catalyst. The equation is $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$. If 4.0 mol of H_2 react, how many moles of NH_3 will be produced?

Solution

ANALYZE

What is given in the problem? **the balanced equation, and the amount of H_2 in moles**

What are you asked to find? **the amount of NH_3 produced in moles**

Organization of data is extremely important in dealing with stoichiometry problems. You will find that it is most helpful to make data tables such as the following one.

Items	**Data**	
Substance	H_2	NH_3
Coefficient in balanced equation	3	2
Molar mass	NA*	NA
Amount	4.0 mol	? mol
Mass of substance	NA	NA

*NA means *not applicable to the problem*

PLAN

What steps are needed to calculate the amount of NH_3 that can be produced from 4.0 mol H_2?

Multiply by the mole ratio of NH_3 to H_2 determined from the coefficients of the balanced equation.

$$\overset{2}{\text{Amount of } H_2 \text{ in mol}} \xrightarrow[\text{multiply by mole ratio: } \frac{NH_3}{H_2}]{} \overset{3}{\text{Amount of } NH_3 \text{ in mol}}$$

$$\overset{\text{given}}{\text{mol } H_2} \times \overset{\text{mole ratio}}{\frac{2 \text{ mol } NH_3}{3 \text{ mol } H_2}} = \text{mol } NH_3$$

COMPUTE

$$4.0\,\text{mol}\,H_2 \times \frac{2\,\text{mol}\,NH_3}{3\,\text{mol}\,H_2} = 2.7\,\text{mol}\,NH_3$$

EVALUATE

Are the units correct?
Yes; the answer has the correct units of moles NH_3.

Is the number of significant figures correct?
Yes; two significant figures is correct because data were given to two significant figures.

Is the answer reasonable?
Yes; the answer is 2/3 of 4.0.

Practice

1. How many moles of sodium will react with water to produce 4.0 mol of hydrogen in the following reaction?

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$ **ans: 8.0 mol Na**

2. How many moles of lithium chloride will be formed by the reaction of chlorine with 0.046 mol of lithium bromide in the following reaction?

$$2LiBr(aq) + Cl_2(g) \rightarrow 2LiCl(aq) + Br_2(l)$$ **ans: 0.046 mol LiCl**

Sample Problem Set *continued*

3. Aluminum will react with sulfuric acid in the following reaction.

$$2Al(s) + 3H_2SO_4(l) \rightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$$

a. How many moles of H_2SO_4 will react with 18 mol Al? **ans: 27 mol H_2SO_4**

b. How many moles of each product will be produced?
ans: 27 mol H_2, 9 mol $Al_2(SO_4)_3$

4. Propane burns in excess oxygen according to the following reaction.

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

a. How many moles each of CO_2 and H_2O are formed from 3.85 mol of propane? **ans: 11.6 mol CO_2, 15.4 mol H_2O**

b. If 0.647 mol of oxygen is used in the burning of propane, how many moles each of CO_2 and H_2O are produced? How many moles of C_3H_8 are consumed? **ans: 0.388 mol CO_2, 0.518 mol H_2O, 0.129 mol C_3H_8**

Sample Problem 2

Potassium chlorate is sometimes decomposed in the laboratory to generate oxygen. The reaction is $2KClO_3(s) \rightarrow 2KCl(s) + 3O_2(g)$. What mass of $KClO_3$ do you need to produce 0.50 mol O_2?

Solution

ANALYZE

What is given in the problem? **the amount of oxygen in moles**

What are you asked to find? **the mass of potassium chlorate**

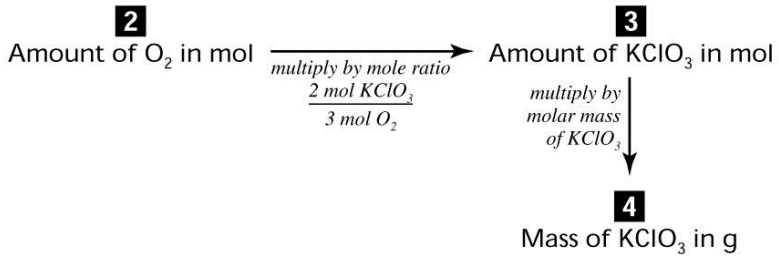
Items	Data	
Substance	$KClO_3$	O_2
Coefficient in balanced equation	2	3
Molar mass*	122.55 g/mol	NA
Amount	? mol	0.50 mol
Mass	? g	NA

*determined from the periodic table

PLAN

What steps are needed to calculate the mass of $KClO_3$ needed to produce 0.50 mol O_2?

Use the mole ratio to convert amount of O_2 to amount of $KClO_3$. Then convert amount of $KClO_3$ to mass of $KClO_3$.



$$\overset{given}{\text{mol O}_2} \times \frac{\overset{mole\ ratio}{2\ \text{mol KClO}_3}}{3\ \text{mol O}_2} \times \frac{\overset{molar\ mass\ KClO_3}{122.55\ \text{g KClO}_3}}{1\ \text{mol KClO}_3} = \text{g KClO}_3$$

COMPUTE

$$0.50\ \text{mol O}_2 \times \frac{2\ \text{mol KClO}_3}{3\ \text{mol O}_2} \times \frac{122.55\ \text{g KClO}_3}{1\ \text{mol KClO}_3} = 41\ \text{g KClO}_3$$

EVALUATE

Are the units correct?

Yes; units canceled to give grams of $KClO_3$.

Is the number of significant figures correct?
Yes; two significant figures is correct.

Is the answer reasonable?
Yes; 41 g is about 1/3 of the molar mass of $KClO_3$, and 0.5 × 2/3 = 1/3.

Practice

1. Phosphorus burns in air to produce a phosphorus oxide in the following reaction:

$$4P(s) + 5O_2(g) \rightarrow P_4O_{10}(s)$$

   a. What mass of phosphorus will be needed to produce 3.25 mol of P_4O_{10}?
   ans: 403 g P

   b. If 0.489 mol of phosphorus burns, what mass of oxygen is used? What mass of P_4O_{10} is produced? **ans: 19.6 g O2, 15.4 g P_2O_4**

2. Hydrogen peroxide breaks down, releasing oxygen, in the following reaction:

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

   a. What mass of oxygen is produced when 1.840 mol of H_2O_2 decomposes?
   ans: 29.44 g O_2

   b. What mass of water is produced when 5.0 mol O_2 is produced by this reaction? **ans: 180 g H_2O**

Sample Problem 3

How many moles of aluminum will be produced from 30.0 kg Al_2O_3 in the following reaction?

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

Solution

ANALYZE

What is given in the problem? **the mass of aluminum oxide**

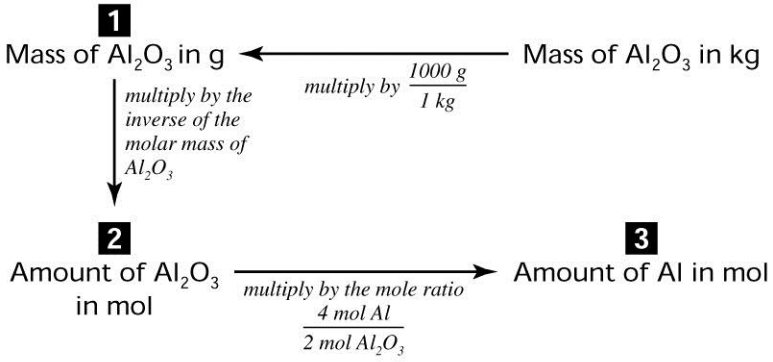
What are you asked to find? **the amount of aluminum produced**

Items	**Data**	
Substance	Al_2O_3	Al
Coefficient in balanced equation	2	4
Molar mass	101.96 g/mol	NA
Amount	? mol	? mol
Mass	30.0 kg	NA

PLAN

What steps are needed to calculate the amount of Al produced from 30.0 kg of Al_2O_3?

The molar mass of Al_2O_3 can be used to convert to moles Al_2O_3. The mole ratio of Al:Al_2O_3 from the coefficients in the equation will convert to moles Al from moles Al_2O_3.



$$\text{kg Al}_2\text{O}_3 \times \frac{1000\ \text{g}}{\text{kg}} \times \frac{1\ \text{mol Al}_2\text{O}_3}{101.96\ \text{g Al}_2\text{O}_3} \times \frac{4\ \text{mol Al}}{2\ \text{mol Al}_2\text{O}_2} = \text{mol Al}$$

given; $\frac{1}{\text{molar mass Al}_2\text{O}_3}$; mole ratio

COMPUTE

$$30.0\ \text{kg Al}_2\text{O}_3 \times \frac{1000\ \text{g}}{\text{kg}} \times \frac{1\ \text{mol Al}_2\text{O}_3}{101.96\ \text{g Al}_2\text{O}_3} \times \frac{4\ \text{mol Al}}{2\ \text{mol Al}_2\text{O}_3} = 588\ \text{mol Al}$$

EVALUATE

Are the units correct?

Yes; units canceled to give moles of Al.

Is the number of significant figures correct?

Yes; three significant figures is correct.

Is the answer reasonable?

Yes; the molar mass of Al_2O_3 is about 100, so 30 kg of Al_2O_3 is about 300 mol. The mole ratio of Al:Al_2O_3 is 2:1, so the answer should be about 600 mol Al.

Practice

1. Sodium carbonate reacts with nitric acid according to the following equation.

$$Na_2CO_3(s) + 2HNO_3 \rightarrow 2NaNO_3 + CO_2 + H_2O$$

   a. How many moles of Na_2CO_3 are required to produce 100.0 g of $NaNO_3$?
   ans: 0.5882 mol Na_2CO_3

   b. If 7.50 g of Na_2CO_3 reacts, how many moles of CO_2 are produced?
   ans: 0.0708 mol CO_2

2. Hydrogen is generated by passing hot steam over iron, which oxidizes to form Fe_3O_4, in the following equation.

$$3Fe(s) + 4H_2O(g) \rightarrow 4H_2(g) + Fe_3O_4(s)$$

   a. If 625 g of Fe_3O_4 is produced in the reaction, how many moles of hydrogen are produced at the same time? **ans: 10.8 mol H_2**

   b. How many moles of iron would be needed to generate 27 g of hydrogen?
   ans: 10. mol Fe

Sample Problem 4

Methane burns in air by the following reaction:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

What mass of water is produced by burning 500. g of methane?

Solution

ANALYZE

What is given in the problem? **the mass of methane in grams**

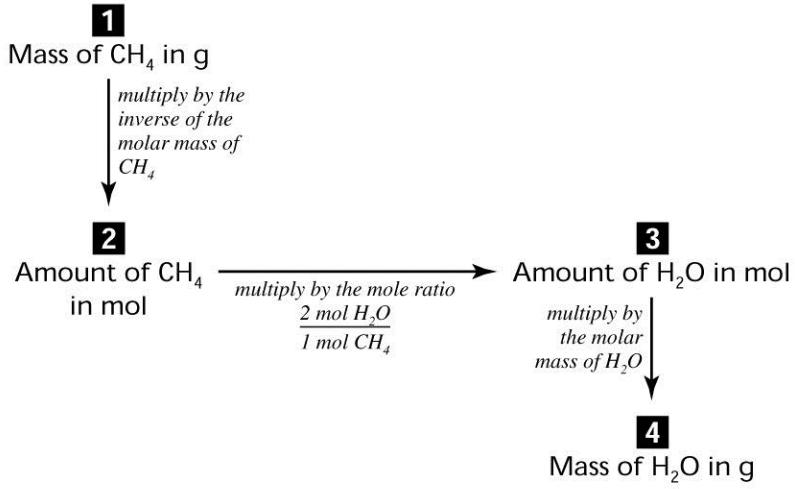
What are you asked to find? **the mass of water produced**

Items	**Data**	
Substance	CH_4	H_2O
Coefficient in balanced equation	1	2
Molar mass	16.05 g/mol	18.02 g/mol
Amount	? mol	? mol
Mass	500. g	? g

PLAN

What steps are needed to calculate the mass of H_2O produced from the burning of 500. g of CH_4?

Convert grams of CH_4 to moles CH_4 by using the molar mass of CH_4. Use the mole ratio from the balanced equation to determine moles H_2O from moles CH_4. Use the molar mass of H_2O to calculate grams H_2O.



$$\overset{given}{\text{g CH}_4} \times \frac{1}{\overset{}{\overbrace{\frac{\text{molar mass CH}_4}{1 \text{ mol CH}_4}}}} \times \overset{mole\ ratio}{\frac{2 \text{ mol H}_2\text{O}}{1 \text{ mol CH}_4}} \times \overset{molar\ mass\ H_2O}{\frac{18.02 \text{ g H}_2\text{O}}{1 \text{ mol H}_2\text{O}}} = \text{g H}_2\text{O}$$

COMPUTE

$$500.\text{ g } CH_4 \times \frac{1 \text{ mol } CH_4}{16.05 \text{ g } CH_4} \times \frac{2 \text{ mol } H_2O}{1 \text{ mol } CH_4} \times \frac{18.02 \text{ g } H_2O}{1 \text{ mol } H_2O} = 1.12 \times 10^3 \text{ g } H_2O$$

EVALUATE

Are the units correct?

Yes; mass of H_2O was required, and units canceled to give grams H_2O.

Is the number of significant figures correct?

Yes; three significant figures is correct because the mass of CH_4 was given to three significant figures.

Is the answer reasonable?

Yes; CH_4 and H_2O have similar molar masses, and twice as many moles of H_2O are produced as moles CH_4 burned. So, you would expect to get a little more than 1000 g of H_2O.

Practice

1. Calculate the mass of silver bromide produced from 22.5 g of silver nitrate in the following reaction:

   $2AgNO_3(aq) + MgBr_2(aq) \rightarrow 2AgBr(s) + Mg(NO_3)_2(aq)$ **ans: 24.9 g AgBr**

2. What mass of acetylene, C_2H_2, will be produced from the reaction of 90. g of calcium carbide, CaC_2, with water in the following reaction?

   $CaC_2(s) + 2H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(s)$ **ans: 37 g C_2H_2**

3. Chlorine gas can be produced in the laboratory by adding concentrated hydrochloric acid to manganese(IV) oxide in the following reaction:

   $MnO_2(s) + 4HCl(aq) \rightarrow MnCl_2(aq) + 2H_2O(l) + Cl_2(g)$

   a. Calculate the mass of MnO_2 needed to produce 25.0 g of Cl_2.
   ans: 30.7 g MnO_2

   b. What mass of $MnCl_2$ is produced when 0.091 g of Cl_2 is generated?
   ans: 0.16 g $MnCl_2$

Additional Problems

1. How many moles of ammonium sulfate can be made from the reaction of 30.0 mol of NH_3 with H_2SO_4 according to the following equation?

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

2. In a very violent reaction called a thermite reaction, aluminum metal reacts with iron(III) oxide to form iron metal and aluminum oxide according to the following equation:

$$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$$

   a. What mass of Al will react with 150 g of Fe_2O_3?

   b. If 0.905 mol Al_2O_3 is produced in the reaction, what mass of Fe is produced?

   c. How many moles of Fe_2O_3 will react with 99.0 g of Al?

3. As you saw in Sample Problem 1, the reaction $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$ is used to produce ammonia commercially. If 1.40 g of N_2 are used in the reaction, how many grams of H_2 will be needed?

4. What mass of sulfuric acid, H_2SO_4, is required to react with 1.27 g of potassium hydroxide, KOH? The products of this reaction are potassium sulfate and water.

5. Ammonium hydrogen phosphate, $(NH_4)_2HPO_4$, a common fertilizer, is made from reacting phosphoric acid, H_3PO_4, with ammonia.

   a. Write the equation for this reaction.

   b. If 10.00 g of ammonia react, how many moles of fertilizer will be produced?

   c. What mass of ammonia will react with 2800 kg of H_3PO_4?

6. The following reaction shows the synthesis of zinc citrate, a ingredient in toothpaste, from zinc carbonate and citric acid.

$$3ZnCO_3(s) + 2C_6H_8O_7(aq) \rightarrow Zn_3(C_6H_5O_7)_2(aq) + 3H_2O(l) + 3CO_2(g)$$

   a. How many moles of $ZnCO_3$ and $C_6H_8O_7$ are required to produce 30.0 mol of $Zn_3(C_6H_5O_7)_2$?

   b. What quantities, in kilograms, of H_2O and CO_2 are produced by the reaction of 500. mol of citric acid?

7. Methyl butanoate, an oily substance with a strong fruity fragrance, can be made by reacting butanoic acid with methanol according to the following equation:

$$C_3H_7COOH + CH_3OH \rightarrow C_3H_7COOCH_3 + H_2O$$

   a. What mass of methyl butanoate is produced from the reaction of 52.5 g of butanoic acid?

   b. In order to purify methyl butanoate, water must be removed. What mass of water is produced from the reaction of 5800. g of methanol?

Sample Problem Set *continued*

8. Ammonium nitrate decomposes to yield nitrogen gas, water, and oxygen gas in the following reaction:

$$2NH_4NO_3 \rightarrow 2N_2 + O_2 + 4H_2O$$

   a. How many moles of nitrogen gas are produced when 36.0 g of NH_4NO_3 reacts?

   b. If 7.35 mol of H_2O are produced in this reaction, what mass of NH_4NO_3 reacted?

9. Lead(II) nitrate reacts with potassium iodide to produce lead(II) iodide and potassium nitrate. If 1.23 mg of lead nitrate are consumed, what is the mass of the potassium nitrate produced?

10. A car battery produces electrical energy with the following chemical reaction:

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$$

    If the battery loses 0.34 kg of lead in this reaction, how many moles of lead(II) sulfate are produced?

11. In a space shuttle, the CO_2 that the crew exhales is removed from the air by a reaction within canisters of lithium hydroxide. On average, each astronaut exhales about 20.0 mol of CO_2 daily. What mass of water will be produced when this amount reacts with LiOH? The other product of the reaction is Li_2CO_3.

12. Water is sometimes removed from the products of a reaction by placing them in a closed container with excess P_4O_{10}. Water is absorbed by the following reaction:

$$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$$

   a. What mass of water can be absorbed by 1.00×10^2 g of P_4O_{10}?

   b. If the P_4O_{10} in the container absorbs 0.614 mol of water, what mass of H_3PO_4 is produced?

   c. If the mass of the container of P_4O_{10} increases from 56.64 g to 63.70 g, how many moles of water are absorbed?

13. Ethanol, C_2H_5OH, is considered a clean fuel because it burns in oxygen to produce carbon dioxide and water with few trace pollutants. If 95.0 g of H_2O are produced during the combustion of ethanol, how many grams of ethanol were present at the beginning of the reaction?

14. Sulfur dioxide is one of the major contributors to acid rain. Sulfur dioxide can react with oxygen and water in the atmosphere to form sulfuric acid, as shown in the following equation:

$$2H_2O(l) + O_2(g) + 2SO_2(g) \rightarrow 2H_2SO_4(aq)$$

    If 50.0 g of sulfur dioxide from pollutants reacts with water and oxygen found in the air, how many grams of sulfuric acid can be produced? How many grams of oxygen are used in the process?

Sample Problem Set *continued*

15. When heated, sodium bicarbonate, $NaHCO_3$, decomposes into sodium carbonate, Na_2CO_3, water, and carbon dioxide. If 5.00 g of $NaHCO_3$ decomposes, what is the mass of the carbon dioxide produced?
16. A reaction between hydrazine, N_2H_4, and dinitrogen tetroxide, N_2O_4, has been used to launch rockets into space. The reaction produces nitrogen gas and water vapor.
    a. Write a balanced chemical equation for this reaction.
    b. What is the mole ratio of N_2O_4 to N_2?
    c. How many moles of N_2 will be produced if 20 000 mol of N_2H_4 are used by a rocket?
    d. How many grams of H_2O are made when 450. kg of N_2O_4 are consumed?
17. Joseph Priestley is credited with the discovery of oxygen. He produced O_2 by heating mercury(II) oxide, HgO, to decompose it into its elements. How many moles of oxygen could Priestley have produced if he had decomposed 517.84 g of mercury oxide?
18. Iron(III) chloride, $FeCl_3$, can be made by the reaction of iron with chlorine gas. How much iron, in grams, will be needed to completely react with 58.0 g of Cl_2?
19. Sodium sulfide and cadmium nitrate undergo a double-displacement reaction, as shown by the following equation:

$$Na_2S + Cd(NO_3)_2 \rightarrow 2NaNO_3 + CdS$$

    What is the mass, in milligrams, of cadmium sulfide that can be made from 5.00 mg of sodium sulfide?
20. Potassium permanganate and glycerin react explosively according to the following equation:

$$14KMnO_4 + 4C_3H_5(OH)_3 \rightarrow 7K_2CO_3 + 7Mn_2O_3 + 5CO_2 + 16H_2O$$

    a. How many moles of carbon dioxide can be produced from 4.44 mol of $KMnO_4$?
    b. If 5.21 g of H_2O are produced, how many moles of glycerin, $C_3H_5(OH)_3$, were used?
    c. If 3.39 mol of potassium carbonate are made, how many grams of manganese(III) oxide are also made?
    d. How many grams of glycerin will be needed to react with 50.0 g of $KMnO_4$? How many grams of CO_2 will be produced in the same reaction?
21. Calcium carbonate found in limestone and marble reacts with hydrochloric acid to form calcium chloride, carbon dioxide, and water according to the following equation:

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$$

    a. What mass of HCl will be needed to produce 5.00×10^3 kg of $CaCl_2$?
    b. What mass of CO_2 could be produced from the reaction of 750 g of $CaCO_3$?

Sample Problem Set *continued*

22. The fuel used to power the booster rockets on the space shuttle is a mixture of aluminum metal and ammonium perchlorate. The following balanced equation represents the reaction of these two ingredients:

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

a. If 1.50×10^5 g of Al react, what mass of NH_4ClO_4, in grams, is required?

b. If aluminum reacts with 620 kg of NH_4ClO_4, what mass of nitrogen monoxide is produced?

23. Phosphoric acid is typically produced by the action of sulfuric acid on rock that has a high content of calcium phosphate according to the following equation:

$$3H_2SO_4 + Ca_3(PO_4)_2 + 6H_2O \rightarrow 3[CaSO_4\ 2H_2O] + 2H_3PO_4$$

a. If 2.50×10^5 kg of H_2SO_4 react, how many moles of H_3PO_4 can be made?

b. What mass of calcium sulfate dihydrate is produced by the reaction of 400. kg of calcium phosphate?

c. If the rock being used contains 78.8% $Ca_3(PO_4)_2$, how many metric tons of H_3PO_4 can be produced from 68 metric tons of rock?

24. Rusting of iron occurs in the presence of moisture according to the following equation:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

Suppose that 3.19% of a heap of steel scrap with a mass of 1650 kg rusts in a year. What mass will the heap have after one year of rusting?