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
→ 1 turkey-and-cheese sandwich

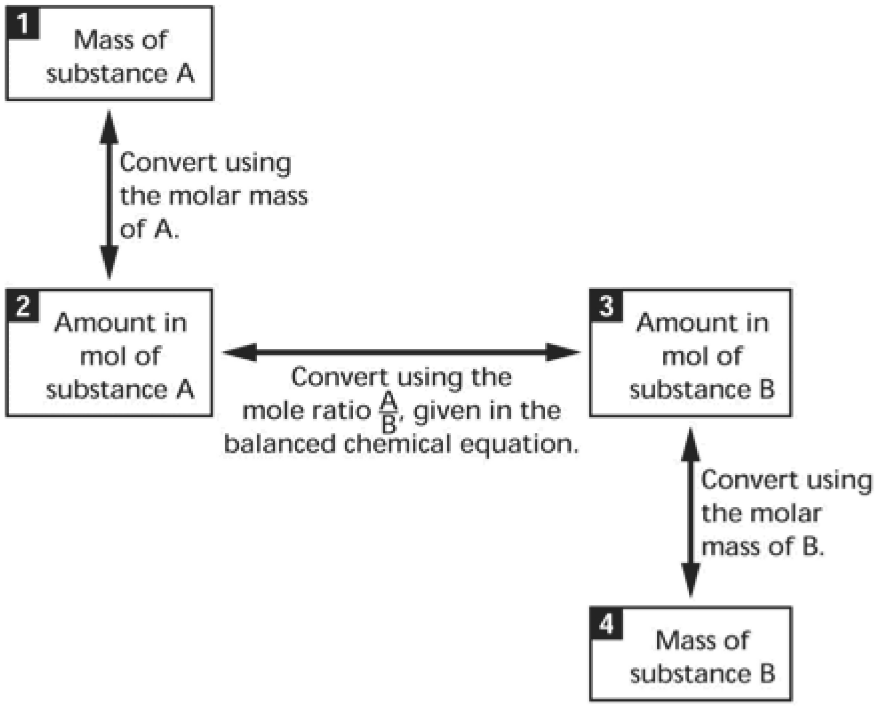
This equation shows that you need those ingredients in a ratio of 2:2:1:1, respectively. You can use this equation to predict that you would need 30 turkey slices to make 15 sandwiches or 6 cheese slices to go with 12 turkey slices.

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.

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**

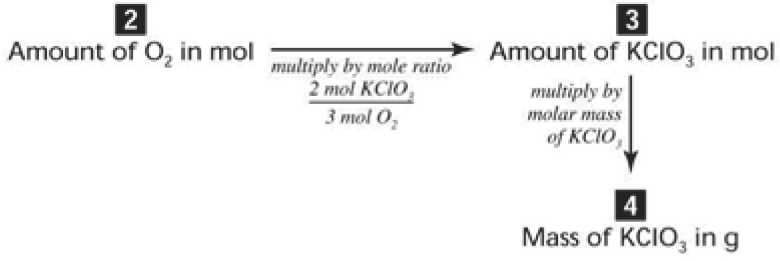
Items	Data	
Substance	$KClO_3$	O_2
Coefficient in balanced equation	2	3
Molar mass*	122.55 g/mol	NA
Amount	? mol	0.50 mol
Mass	? g	NA

*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 $KClO_3$.



$$\underset{\text{mol } O_2}{\overset{\text{given}}{}} \times \frac{\overset{\text{mole ratio}}{2 \text{ mol } KClO_3}}{3 \text{ mol } O_2} \times \frac{\overset{\text{molar mass } KClO_3}{122.55 \text{ g } KClO_3}}{1 \text{ mol } KClO_3} = \text{g } KClO_3$$

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**

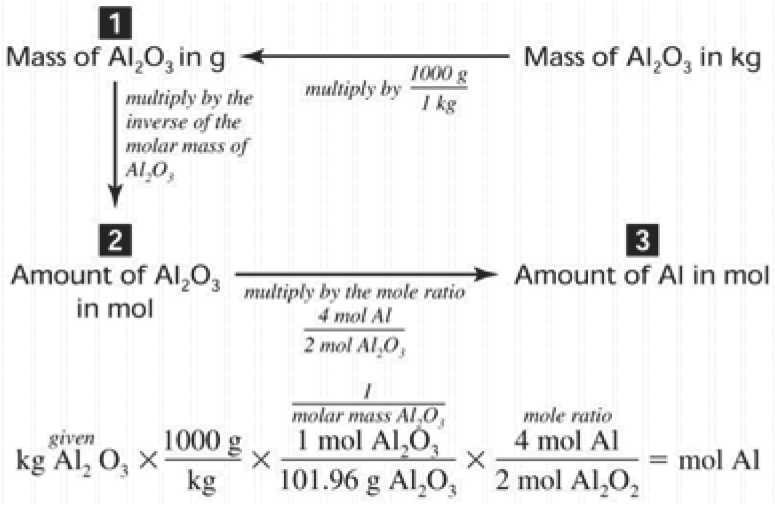
What are you asked to find? **the amount of aluminum produced**

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.



COMPUTE

$$30.0 \text{ kg } Al_2O_3 \times \frac{1000 \text{ g}}{\text{kg}} \times \frac{1 \text{ mol } Al_2O_3}{101.96 \text{ g } Al_2O_3} \times \frac{4 \text{ mol Al}}{2 \text{ mol } Al_2O_3} = 588 \text{ mol Al}$$

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**

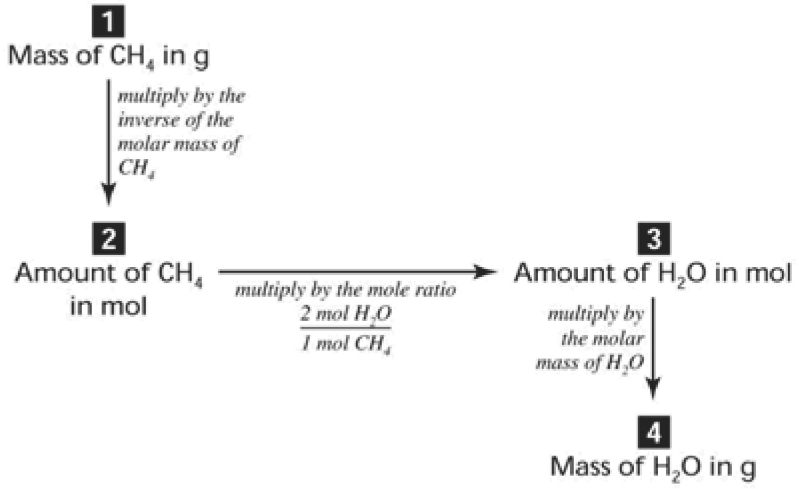
What are you asked to find? **the mass of water produced**

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.



$$\overset{given}{\text{g CH}_4} \times \frac{\overset{1}{\overbrace{\phantom{1\text{ mol CH}_4}}}}{\underset{\text{molar mass CH}_4}{\underbrace{16.05\text{ g CH}_4}}} \times \frac{\overset{\text{mole ratio}}{\overbrace{2\text{ mol H}_2\text{O}}}}{1\text{ mol CH}_4} \times \frac{\overset{\text{molar mass H}_2\text{O}}{\overbrace{18.02\text{ g H}_2\text{O}}}}{1\text{ mol H}_2\text{O}} = \text{g H}_2\text{O}$$

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 $MnCl_2$