Chapter 9 – Chemical Quantities

1) As you have begun to see, chemistry is a quantitative science involving a great deal of calculations. However, the purpose of these calculations is not merely to get a number, but also to provide quantitative predictions or descriptions of how matter behaves. Correctly calculating the amount of product that is produced in a chemical reaction shows that we understand something about what is really going on in the reaction, and it allows us to use the reaction to produce a desired amount of product. Calculations are tools chemists use in understanding and using the behavior of matter.

   One category of chemical calculations involves relationships between quantities of reactants and products based upon relationships given in the balanced equation for any reaction. This is why we learned how to balance chemical equations in Chapter 7 and kept it as part of our discussions in Chapter 8. Determination of quantities of reactants required for reaction, choosing the amount of reactant necessary to give a desired amount of product, calculation of the concentration of a solution (Chapter 15), determination of percent composition as a check for purity (Chapter 6), and identification of the empirical and molecular formula of an unknown product (Chapter 6) all fall into this category, which is generally called **chemical stoichiometry**.

   Stoichiometry is a more formal term chemists use when they talk about the quantities involved in chemical reactions. It is also a term which is used to describe the process of using a chemical equation to calculate the relative masses of reactants and products involved in a reaction. Simply put, stoichiometry is the calculation of quantities in chemical equations/reactions.

2) Sec 9.1 – Information Given by Chemical Equations
   a) The coefficients in a chemical equation carry a dual meaning: "number of formula units (particles) or molecules or atoms" at the microscopic level and "number of moles" at the macroscopic level. The coefficients of a balanced chemical equation give you the relative number of moles of reactants and products in the chemical reaction.

   b) REMEMBER: In a chemical reaction, only mass and atoms are conserved. Moles, molecules, formula units, and volumes are not generally conserved.

3) Sec 9.2 – Mole-Mole Relationships

   The relative numbers of moles of the various species participating in a reaction are provided by the chemical equation that describes the system.

   A. Consider the reaction: $2\ H_2 + O_2 \longrightarrow 2\ H_2O$. This chemical equation tells us that 2 molecules of hydrogen (remember that hydrogen is diatomic!) react with 1 molecule of oxygen (ditto) to form 2 molecules of water. We can also now see that this same equation can tell us that 2 **moles** of hydrogen react with 1 **mole** of oxygen to produce 2 **moles** of water.

      From this we can see several relationships:
      i) 2 moles of hydrogen always produce 2 moles of water
      ii) 1 mole of oxygen is needed to produce 2 moles of water
      iii) 1 mole of oxygen needs 2 moles of hydrogen to react completely

B. How about the reaction: $2\ C_8H_{18} + 25\ O_2 \longrightarrow 16\ CO_2 + 18\ H_2O$?

or $N_2 + 3\ H_2 \longrightarrow 2\ NH_3$

4) Steps in Calculating Quantities in a Chemical Reaction (Doing a Stoichiometric Calculation)

a) Write a balanced chemical equation describing the reaction that occurs.

b) Calculate the number of moles (n) of what is given.

1) Mass (convert to grams if necessary): $n = \frac{\text{mass (g)}}{\text{molar mass}}$

2) Volume of a Liquid (use density to get mass in grams): $n = \frac{\text{mass (g)}}{\text{molar mass}}$

3) Molecules: $n = \frac{\text{\# of molecules}}{6.02 \times 10^{23}}$

4) Volume of a Gas at STP (convert volume to liters if necessary): $n = \frac{\text{volume (L)}}{22.4\ \text{L}}$

c) Use the reaction coefficients (a and b) and the moles of the given to calculate the moles of the unknown:

Multiply by the ratio: $\frac{\text{b (moles of unknown)}}{\text{a (moles of given)}}$

d) Convert the moles of the unknown into the desired quantity using the equations given in part b.

5) Sec 9.3 and 9.4 – Mole-Mole and Mass-Mass Calculations – Examples

a) How many moles of chlorine gas will be required to react with excess iron to produce 14 moles of iron(III) chloride?

b) How many grams of hydrogen can be produced by the reaction of 5.585 g of iron reacting with excess hydrochloric acid?

c) How many grams of aluminum must react with excess oxygen to produce 20.4 g of aluminum oxide?

6) Other Stoichiometric Calculations – Examples

a) How many grams of glucose, $C_6H_{12}O_6$, must be burned to produce 5.6 L of CO_2 at STP?

b) What volume of oxygen gas at STP is needed to burn 200 mL of butane, C_4H_{10}? (Butane is a liquid with a density of 0.60 g/mL.)

c) One way to remove carbon dioxide from air in a spacecraft is to react it with LiOH. A person in one day exhales about 1.0 Kg of carbon dioxide. How many grams of LiOH are needed to remove the carbon dioxide from the air on a six-day lunar mission with three astronauts, and at the same time have 25% of the LiOH left after the mission?

7) Sec 9.5 – Comparing Two Reactions – Mass and Mole Relationships in a Chemical Reaction

Have you ever listened to or read advertisements for different products, each of which says it is better in doing a certain task? Sometimes these ads can illustrate how chemical calculations can be important in everyday life. What are they talking about?

Consider two common compounds that are often used as antacids: baking soda, $NaHCO_3$ and milk of magnesia or magnesium hydroxide (in water), $Mg(OH)_2$. Both of these compounds will react with the excess hydrochloric acid which can be secreted by the stomach.

The reactions are:

a. $NaHCO_3 + HCl \longrightarrow NaCl + H_2O + CO_2$

b. $Mg(OH)_2 + 2\ HCl \longrightarrow MgCl_2 + H_2O$

A question we could ask is which antacid can consume the most stomach acid, 1.00 g $NaHCO_3$ or 1.00 g $Mg(OH)_2$?

8) Sec 9.6 and 9.7 – Limiting Reagent
   a) Limiting Reagent limits or determines the amount of product that can be formed in a reaction.

   b) Excess Reagent is present in an amount that is more than enough to react with all of the limiting reagent. Some of the excess reagent is left over.

   Example – How many grams of NO can be produced by the reaction of 6.35 g of copper with 18.9 g of nitric acid? What reagent is in excess, and what mass of the excess reagent will remain after the reaction? $3\ Cu + 8\ HNO_3 \text{ ----> } 3\ Cu(NO_3)_2 + 2\ NO + 4\ H_2O$

   Example – How many grams of water are needed to react with exactly 249 g of methane according to the balanced equation $CH_4 + H_2O \longrightarrow 3H_2 + CO$?

9) Sec 9.8 – Percent Yield
   a) Theoretical Yield – is the maximum amount of product that can be produced from the stated amount of reactants. It is a calculated number. Calculated from stoichiometry.

   b) Actual Yield – is the amount of product obtained when the reaction is actually done in the laboratory. It is an experimentally measured value. It can never be greater than the theoretical yield. It is given or you measure it.

   c) Percent Yield

$$\text{percent yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

Example – A mixture of 80g of chromium oxide and 8.0 g of carbon experimentally produces 21.7 g of chromium. What is the percent yield of the Cr? The chemical equation for this reaction is: $Cr_2O_3 + 3\ C \dashrightarrow 2\ Cr + 3\ CO$

Example – Before beginning a lab, a student read that the percent yield for a difficult reaction to be studied was likely to be only 40.0% of the theoretical yield. Her prelab stoichiometric calculations predict that the theoretical yield should be 12.5 g. What is her actual yield likely to be?