Chemical Reactions in Solution

Objectives: By the end of todays class you will be able to

- calculate the molarity of a solution,
- determine the limiting reagent of a chemical reaction,
- perform stoichiometric calculations for a reaction with a limiting reactant.

4.3: Chemical Reactions in Solution

- **Solutions** are composed of a **solvent** and one or more **solutes**.
- The **solvent** is present in the largest amount. For our purposes the solvent = H_2O.
- **Solute** is present in smaller amounts and is dissolved in the solvent.
- Solutions are homogenous (have uniform properties).

Molarity

Describes the concentration of the solution.

$$\text{Molarity} = \frac{\text{amount of solute (moles)}}{\text{volume of solution (liters)}}$$

$$C = \frac{n}{V}$$

The symbol M stands for mol/l.

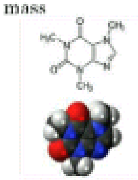
$M = mol/l$

Example 1: Coffee!

What is the caffeine concentration of a cup of instant coffee? The instructions on the coffee say to add 1 teaspoon (~2 g) of coffee per 250 ml of water.

Data: $M_{caffeine} = 194.19 \frac{g}{mol}$

instant coffee is 3.142% caffeine by mass



$c = \frac{\text{moles caffeine}}{\text{volume coffee}}$

$2g \times \frac{3.142g}{100g} \times \frac{1\ mol}{194.19g} = 3.24 \times 10^{-4}\ mol$

$c = \frac{3.24 \times 10^{-4}}{0.250} M$

Caffeine Concentrations/Serving

www.redbull.ca

Example 2:

Aqueous solutions of **sodium hypochlorite (NaClO)** can be used in the synthesis of **hydrazine (N_2H_4)**. Hydrazine has often been used as a rocket fuel for engines in the orbital maneuvering system of the space shuttle.

A solution is prepared by **dissolving 45.0 g of NaClO** in enough water to produce exactly **750 ml of solution**.

What is the molarity of the solution?

$M_{NaClO} = 74.4\ g/mol$

$45.0g \times \frac{1\ mol}{74.4g} = 0.605\ mol$

$0.605\ mol / 0.750\ L = ANS$

Ways to Express Concentration

- percentages
  - by mass
    - Ex: 25% (w/w) = 25 g solute per 100 g solution
  - by volume
    - Ex: 25% (v/v) = 25 ml solute per 100 ml solution
  - weight to volume
    - Ex: 25% (w/v) = 25 g solute per 100 ml solution
- mole fraction $x_i = \frac{n_i}{n_1 + n_2 + ... + n_n} = \frac{n_i}{\sum_{j=1}^{n} n_j}$ $\quad \sum_{j=1}^{n} x_j = 1$
- molarity = $\frac{\text{amount of solute (moles)}}{\text{volume of solution (liters)}}$
- molality = $\frac{\text{amount of solute (moles)}}{\text{amount of solution (kg)}}$

4.4: Determining the Limiting Reactant

I bought 1 dozen eggs, a 2 lb bag of sugar, a 2 lb bag of flour, 1 lb of butter and 1 4 oz bottle of vanilla extract.

What is the limiting reactant?

How many waffles can I make?

The Limiting Reactant

- The reactant that is completely consumed.
- The other reactants are called excess reactants.
- Ex. CO and O_2 react as to form CO_2 as follows:

$$2\,CO + O_2 \rightarrow 2\,CO_2$$

If you have 1.0 mol CO and 1.0 mol O_2 what is the limiting reactant?

In stoichometric calculations you must use the limiting reactant as the basis!

Suggested Readings

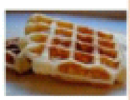
4.3 Chemical Reactions in Solution
4.4 Determining the Limiting Reactant

Belgian Sugar Waffle Recipe

Soften 250 g butter so that it is almost melted. Beat in 250 g sugar. Beat in 4 eggs, one by one. Beat in 250 g flour, 1 tbs vanilla extract and 1 tbs vegetable oil. Beat until the mixture is homogenous.

Heat waffle iron and bake waffles. Allow waffles to cool on a cooling rack and eat as cookies.

Makes ~ 2 dozen waffles ☺



Example 3: The fuel hydrazine can be produced by the reaction of solutions of sodium hypochlorite and ammonia:

$$NaClO(aq) + 2\ NH_3(aq) \rightarrow N_2H_4(aq) + NaCl(aq) + H_2O(l)$$

If 750 ml of 0.806 M NaClO is mixed with excess ammonia, how many moles of hydrazine can be formed?

If the final volume of the resulting solution is 1.25 l, what will be the molarity of the hydrazine?

Basis: 750ml of 0.806 mol/l solution

Data:

$$0.750\,l \times \frac{0.806\,mol}{1\,l} \times \frac{1\ mol\ N_2H_4}{1\ mol\ NaClO} = 0.605\ mol$$

$$C = \frac{0.605\ mol}{1.25\,l}$$

Example 4: Nitrogen gas can be prepared by passing gaseous ammonia over solid copper (II) oxide at high temperatures. The other products of the reaction are solid copper and water vapor.

$$2NH_3\ (g) + 3CuO\ (s) \rightarrow N_2\ (g) + 3Cu\ (s) + 3H_2O\ (g)$$

If 18.1 g of NH_3 is reacted with 90.4 g of CuO, which is the limiting reactant?
How many grams of N_2 will be formed?

	m	M (g/mol)	n (moles)
NH_3	18.1	17.03	1.06
CuO	90.4	79.546	1.14

$\because \frac{CuO}{NH_3} = 1.5$ && $1.14 < 1.5$

$\therefore$ CuO is the limiting reagent.

$$1.14\ mol\ CuO \times \frac{1\ mol\ N_2}{3\ mol\ CuO} \times \frac{28.014\,g\ N_2}{1\ mol\ N_2} = ANS$$

Example 5: The solid fuel booster rockets of the space shuttle are based on the following reaction between ammonium perchlorate and aluminum.

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

813 g 187 g

If either reactant is in excess, unnecessary mass will be added to the shuttle, so a stoichiometric mixture is desired.

What mass of reactants should be used for every 1.00 kg of the fuel mixture?

$\because$ ratio is 1-1

$\therefore n_{Al} = n_{NH_4ClO}$

method #1

let x = # of moles

$$\frac{m_{Al}}{M_{Al}} = \frac{\overset{1000 - m_{Al}}{m_{NH_4ClO}}}{M_{NH_4ClO}}$$