Experiment 4
Limiting Reactant

> *Note*:
> Please be sure that you review the following concepts and ideas before you come to the lab.:
> Mole, atomic mass (AM), molar mass (MM), calculations of the number of moles from mass and AM or MM.

The amounts of the products in chemical reactions may be determined by controlling the relative amounts of reactants. The reactants may be mixed according to the stoichiometry of the reaction. In this case, the mixing is called stoichiometric mixing and no limiting reactant involved. If the mixing is not according to the stoichiometry of the reaction it is called none-stoichiometric mixing, and the progress of the reaction is controlled by one of the reactants, called limiting reactant. Of course, the other reactants are in excess. Controlling the reaction means controlling the amounts of the products and the unreacted excess reactants. All of the limiting reactant is consumed in the chemical reaction.

<u>The concept of limiting reactant</u>:

The basic requirement for stoichiometric calculations is BALANCED CHEMICAL EQUATION. Otherwise, no correct calculations are produced.

Consider the following two examples:

$$CH_{4(g)} + H_2O_{(g)} \longrightarrow 3H_{2(g)} + CO_{(g)} \quad .... \ (1)$$

The chemical equation is balanced; the mole ration of the reactants is 1:1.

Any mixing ratio that is different from one to one is called none stoichiometric and the reaction must involve a limiting reactant.

The mixing ratio in the following example is 3:1.

$$3H_{2(g)} + N_{2(g)} \rightarrow 2NH_{3(g)} \ldots . \ (2)$$

The concept of limiting reactant may be illustrated through the following table:

Trial #	Reaction #	# moles CH_4 *or* H_2	# moles H_2O *or* N_2	# moles of H_2 Produced	# moles of CO Produced	# moles of NH_3 Produced
1	1	0.50	0.50	1.50	0.50	---
2	1	1.0*	2.2	3.0	1.0	---
3	1	2.6	1.5 *	4.5	1.5	---
4	2	1.5	0.50	---	---	1.0
5	2	3.0 *	3.0	---	---	2.0
6	2	5.0 *	2.0	---	---	3.33
7	2	7.0	2.0 *	---	---	4.0

The (*) indicates the limiting reactant.

According to the table above:

<u>*Reaction 1*</u>:

The first trial is stoichiometric mixing, no excess reactants.

CH_4 is the limiting reactant in the second trial, (1.2 mole of H_2O is unreacted).

H_2O is the limiting reactant in the third trial, (1.1 mol of CH_4 is unreacted).

<u>*Homework*</u>: calculate the amounts masses of H_2 and CO produced in each case.

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Reaction 2:

Trial number 4: The mixing is stoichiometric, no excess reactants.

Trial number 5: The mixing is none stoichiometric, H_2 is limiting reactant, 2.0 moles of N_2 unreacted, 2.0 moles of NH_3 are produced.

Trial number 6: The mixing is none stoichiometric, H_2 is limiting reactant, 0.33 moles of N_2 unreacted, 3.33 moles of NH_3 are produced.

Trial number 7: The mixing is none stoichiometric, N_2 is limiting reactant, 1.0 mole of H_2 unreacted, 4.0 moles of NH_3 are produced.

Homework: calculate the masses number of masses NH_3 produced in each case.

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The number of moles may be converted into masses by the use of the molar masses (MM). All of the numbers in the table above can be converted into masses by the use of the relation below:

$$\text{Mass} = (\text{number of moles})\ (\text{MM})$$

MM (g/mol):

$(CH_4) = 16$; $(NH_3) = 17$; $(CO) = 28$; $H_2 = 2.0$; $N_2 = 28$; $H_2O = 18$

The Experiment:

Solid unknown mixture of $BaCl_2.2H_2O$ and Na_2SO_4

Molecular equation: (balanced)

$$BaCl_2.2H_2O_{(aq)} + Na_2SO_{4\,(aq)} \longrightarrow BaSO_{4\,(s)}\downarrow + 2NaCl_{(aq)}$$

MM(g/mol): $BaCl_2.2H_2O$ = 244.27 ; Na_2SO_4 = 142.05 ; $BaSO_4$ = 233.33

Net ionic equation:

$$Ba^{2+}_{(aq)} + SO_4^{=}{}_{(aq)} \longrightarrow Ba\,SO_{4\,(s)}\downarrow$$

- From the balanced equation:

Number of moles of $BaCl_2.2H_2O$ = number of moles of Na_2SO_4

= number of moles of $BaSO_4$

Fast Look at the procedure:

Part A: Take an exact mass (1-2 g) of the Na_2SO_4 / $BaCl_2.2H_2O$ unknown mixture, add it to about 150 mL of de-ionized water, insoluble barium sulfate, $BaSO_4$, will be formed. Collect the precipitate by filtration, then wash, dry, and weight. Record the mass of your precipitate.

<u>Part B</u>: Determination of the limiting reactant.

This is done through two precipitation tests with solutions of 0.5 M of each of $BaCl_2$ and Na_2SO_4 as follows:

i- Test for excess $SO_4^{=}$:-

Add 2 drops of 0.5 M $BaCl_2$ solution to the <u>supernatant</u>, if a precipitate is formed then it should be $BaSO_4$. This means that (Na_2SO_4) is in excess and $BaCl_2.2H_2O$ is the Limiting Reactant. Otherwise Na_2SO_4 is the L.R. and $BaCl_2.2H_2O$ is in excess.

ii- Test for excess Ba^{2+}:-

Add 2 drops of 0.5 M Na_2SO_4 solution to the <u>supernatant</u>, if a precipitate is formed then it should be $BaSO_4$. This means that ($BaCl_2.2H_2O$) is in excess and $Na_2SO_4$is the Limiting Reactant. Otherwise $BaCl_2.2H_2O$ is the L.R. and Na_2SO_4 is in excess.

<u>*Example*</u>: *(How to do the calculations)*

Consider the following data obtained from a reaction between $BaCl_2.2H_2O$ and Na_2SO_4. The following data were obtained:

The mass of the unknown mixture = 1.59 g

The mass of the precipitate $BaSO_4$ [*after washing and drying*] = 0.188g

The test reveals that the <u>L.R</u> is $BaCl_2.2H_2O$

What is the mass percent of the salt mixture?

<u>*Solution*</u>:

Number of moles of the product $BaSO_4$ = 0.188 g/233.33 g/mol

= 8.056×10^{-4} mol.

From the balanced chemical equation,

# of moles of the L.R ($BaCl_2.2H_2O$) = # moles of $BaSO_4$ = $8.056 \text{X} 10^{-4}$ mol

∴ Mass of $BaCl_2.2H_2O$ = (8.056×10^{-4} mol) (244.27g/mol) = 0.197 g

Mass % ($BaCl_2.2H_2O$) = [0.197 g/1.59 g] x100% = 12.39 %

Mass % (Na_2SO_4) = 100 % − 12.39 % = 87.61%

<u>Experimental procedure</u>:

Some important experimental steps that are done are illustrated below:

- *Digestion*: This is done to encourage the *<u>crystal growth</u>* over *<u>nucleation</u>* process in ordered to have large particle size ppt., which is easier to filter. Digestion process is experimentally governed by controlling heat rate and stirring. It is performed by slow heating (80-90 ^{o}C), with no stirring, and covering the beaker with watch glass. This keeps the particles warm, which increases the crystal growth.
- *Decantation;* *(see the technique in the internet)*
- *Filtration (Gravity filtration);* *(see the technique in the internet)*

Minimum of two trials is recommended

<u>Important Note</u> and Example:

Study the example below between sodium phosphate dodecahydrate and barium chloride dihydrate. Barium phosphate is precipitated in the reaction. The stoichiometric ratio between the reactants is <u>not</u> 1;1. Actually it is 2:3. If the stoichiometric ratio is not 1:1, much more care is required to find the limiting reactant and do the rest of the calculations.

Proper amount of water is added to 0.942 g of an unknown solid mixture of sodium phosphate dodecahydrate, $Na_3(PO_4)_2.12H_2O$, and barium chloride dihydrate, $BaCl_2.2H_2O$. Barium phosphate, $Ba_3(PO_4)_2$, precipitated. The mass of the precipitate after filtration, washing and drying was found to be 0.188g. A test revealed that $BaCl_2.2H_2O$ was the limiting reactant, calculate the masses of the components of the unknown solid mixture and its percentage composition?

Molecular equation:

$$2\ Na_3(PO_4)_2.12H_2O_{(aq)} + 3BaCl_2.2H_2O_{(aq)} \longrightarrow$$

$$Ba_3(PO_4)_{2(s)}\downarrow + 6\ NaCl + 30\ H_2O_{(\ell)}$$

Mass of $Ba_3(PO_4)_{2(s)}$ produced = 0.188 g

Moles of $Ba_3(PO_4)_{2(s)}$ produced = mass / MM

$$= 0.188\ g / 601.93\ g/mol = 3.12\ x10^{-4}\ mole$$

The L.R is $BaCl_2.2H_2O$, so,

Moles of $BaCl_2.2H_2O$ reacted = (3) (moles of $Ba_3(PO_4)_{2(s)}$ produced)

$$= (3) (3.12\ x10^{-4}) = 9.370\ x10^{-4}\ mol.$$

Mass of $BaCl_2.2H_2O$ reacted = (moles) (MM)

$$= (9.370X10^{-4}\ mol) (244.27g/mol) = 0.2289\ g$$

So, mass of $Na_3(PO_4)_2.12H_2O$ = mass of sample – mass of $BaCl_2.2H_2O$

= 0.942 g − 0.2289 g = 0.713g

Mass % of $Na_3(PO_4)_2.12H_2O$ in the sample

= (0.713g / 0.942 g)(100%) = 75.70%

% $BaCl_2.2H_2O$ = 100 % − 75.70% = 24.30 %

The End