Chemistry 11 - Week 6: May 19 – May 22

Anticipated time required: 3 hours

New learning objective: **Limiting and Excess Reactants, Percent Yield**

Goals to be completed:

1. Use basic stoichiometry calculations to solve which reactant limits a reaction, and how much of a reactant may be found in excess
2. Solve the percent yield of a chemical reaction
3. Practice Problems
4. Assignment

This PDF package contains several notes, examples and practice problems. The only formal portion that you are required to submit is the section titled "Formal Assignment to be Submitted". This can be sent to Charlie.feht@yesnet.yk.ca either as a scanned and uploaded PDF attachment to email, or as a jpeg image file.

Upcoming next week:

Solution Chemistry – Polarity of molecules and solutions, ionization and dissociation of molecules in solution

Please watch the following intro videos before you begin the package:

https://www.youtube.com/watch?v=dodsvTfqWNc

https://www.youtube.com/watch?v=ymCZ2ShhBAw

Chemistry 11

Limiting and Excess Reactants

Stoichiometric concepts we have already covered:

1. Using coefficients for stoichiometric calculations
2. Using moles, mass, gas volumes, and particles for stoichiometric calculations
3. Using molar concentration for stoichiometric calculations

And now for the final concept in this unit!! **Limiting and Excess Reactants!**

All of the questions we have been dealing with since the beginning have assumed that all of the given reactants have been fully used up, however this is not the case in real life. Reactions usually have one or more reactants left over. Sometimes chemists will purposely have excess reactants in a reaction to make sure that the other chemical is completely used up in a chemical reaction.

Lets look at an example using tricycles.

If you have 32 wheels and 10 frames, how many tricycles can you make?

Balanced Reaction: 3 Wheels + 1 Frame → 1 Tricycle

Calculation:

32 wheels × $\frac{1 \text{ Tricycle}}{3 \text{ Wheels}}$ → 10.66 tricycles

10 Frames × $\frac{1 \text{ Tricycle}}{1 \text{ Frame}}$ → (10 Tricycles) smaller value limits how many tricycles are made, only 10.

What reactant was used up completely? Frames

This reactant is referred to as the "limiting reactant" because it has limited the amount of product that we could make (in this case, tricycles).

What reactant is left over? ~~Tricycles~~ wheels

This reactant is referred to as the "excess reactant" because we have some left over. How much of this reactant is left over?

Have: 32 wheels

Used: calculate based on limiting reactant

10 Frames × $\frac{3 \text{ wheels}}{1 \text{ Frame}}$ = 30 wheels used

Leftover: # Have − # used

32 − 30 = 2 wheels left over

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A simple way to find excess and limiting reactants is to calculate the mass of some arbitrarily selected product. For example: If 20g of H_2 reacts with 100g of O_2 gas, to form H_2O, which reactant is limiting and which one is in excess?

H_2O

excess

$$2H_2 + O_2 \rightarrow 2H_2O$$

① Mass of H_2O (based on H_2) $= 20g\ H_2 \times \frac{1\ mol\ H_2O}{2g\ H_2} \times \frac{2\ mol\ H_2O}{2\ mol\ H_2} \times \frac{18g\ H_2O}{1\ mol\ H_2O} = 180g\ H_2O$

② Mass of H_2O (based on O_2) $= 100g\ O_2 \times \frac{1\ mol\ O_2}{32g\ O_2} \times \frac{2\ mol\ H_2O}{1\ mol\ O_2} \times \frac{18g\ H_2O}{1\ mol\ H_2O} = 112.5g\ H_2O$

smaller ∴ limiting

There is enough H_2 to make 180g H_2O but only enough O_2 to make 112.5g so O_2 sets a limit on the reaction

Example 2. If 56.8 g of $FeCl_2$, 14.0 g of KNO_3 and 40.0 of HCL are mixed and allowed to react according to the following equation:

I have selected to solve the mass of the product NO simply because it has an easy molar mass to find

Solve potential mass of NO based on the mass of each reactant available

$$3FeCl_2 + KNO_3 + 4HCl \rightarrow 3FeCl_3 + NO + 2H_2O + KCl$$

Reactant 1 Reactant 2 Reactant 3

Which chemical is the LIMITING reactant?

Arbitrarily, Find NO mass based on each reactant

① NO ($FeCl_2$) $= 56.8g\ FeCl_2 \times \frac{1\ mol\ FeCl_2}{126.8g\ FeCl_2} \times \frac{1\ mol\ NO}{3\ mol\ FeCl_2} \times \frac{30g\ NO}{1\ mol\ NO} = 4.48g$

② NO (KNO_3) $= 14.0g\ KNO_3 \times \frac{1\ mol\ KNO_3}{101.1g\ KNO_3} \times \frac{1\ mol\ NO}{1\ mol\ KNO_3} \times \frac{30g\ NO}{1\ mol\ NO} = 4.15g$ limiting

③ NO (HCl) $= 40g\ HCl \times \frac{1\ mol\ HCl}{36.5g\ HCl} \times \frac{1\ mol\ NO}{4\ mol\ HCl} \times \frac{30g\ NO}{1\ mol\ NO} = 8.22g$

How many grams of each EXCESS reactant are actually present in excess?

Solve the stoich calculation for the remaining excess reactants based on the known limiting reactant

① Find mass of $FeCl_2$ / HCl that react based on KNO_3

$FeCl_2$ used $= 14g\ KNO_3 \times \frac{1\ mol\ KNO_3}{101.1g\ KNO_3} \times \frac{3\ mol\ FeCl_2}{1\ mol\ KNO_3} \times \frac{126.8g\ FeCl_2}{1\ mol\ FeCl_2} = 52.7g$

Mass in excess $= 56.8 - 52.7 = 4.1g$ Mass left over

What we started with — What was actually used up

HCl used $= 14g\ KNO_3 \times \frac{1\ mol\ KNO_3}{101.1g\ KNO_3} \times \frac{4\ mol\ HCl}{1\ mol\ KNO_3} \times \frac{36.5g\ HCl}{1\ mol\ HCl} = 20.2g$

mass in excess $= 40.0 - 20.2 = 19.8g$ Mass left over

What we started with — What was actually used up

Percent Yield

- Stoichiometry allows you to predict the amount of product that will be produced BUT
- Sometimes reactants don't completely react
- So the amount we calculate using the balanced reaction and mole ratios is a *theoretical* amount.

- Def: Theoretical Yield: The amount of product calculated using Stoichiometry
- Def: Actual Yield: The amount of product actually made when the reaction is done in a lab.
    - You can think of it like baking pancakes. There is always some batter left in the bowl that doesn't get turned into a pancake…
- Def: Percent Yield = $\frac{\text{actual yield}}{\text{theoretical yield}} x\,100\%$

Why, you might ask?

1. Not all of the pure material will react
2. The reactants may be impure to begin with
3. Some of the products are lost during physical separation

Example1:
What is the percent yield of water if you react 40 grams of Hydrogen with an **excess** of Oxygen and get 340 grams of water?

1. Solve the mass-mass Stoichiometry problem to find the theoretical yield

$$2\ H_2 + O_2 \rightarrow 2H_2O$$

$$40\ \text{g}\ H_2 \times \frac{1\ \text{mol}\ H_2}{2.02g} \times \frac{2\ \text{mol}\ H_2O}{2\ \text{mol}\ H_2} \times \frac{18.02\ \text{g}\ H_2O}{1\ \text{mol}\ H_2O} = 357g\ H_2O$$

2. Find the percent yield

$$\frac{340\ \text{g}}{357\ \text{g}} x\,100\% = 95\%$$

Answer: 95%

Example 2:
How much water can be made if you react 40 grams of Oxygen with an **excess** of hydrogen and the reaction, typically has a 95% yield?

1. Solve the mass-mass Stoichiometry problem to find the theoretical yield.

$$40\text{ g }O_2 \times \frac{1\text{ mol }O_2}{32.00g} \times \frac{2\text{ mol }H_2O}{1\text{ mol }O_2} \times \frac{18.02\text{ g }H_2O}{1\text{ mol }H_2O} = 45\ g\ H_2O$$

2. Set up the % yield equation and solve for actual yield

$$95\% = \frac{X}{45\text{ g}} x\,100\% \rightarrow .95 = \frac{X}{45\text{ g}} \rightarrow .95 \times 45g = 43g$$

Answer: 43 grams of water

Practice Problems **Limiting Reagent Worksheet #1**

1. Given the following reaction: (Balance the equation first!)

$$C_3H_8 + O_2 \text{ -------> } CO_2 + H_2O$$

a) If you start with 14.8 g of C_3H_8 and 3.44 g of O_2, determine the limiting reagent

b) determine the number of moles of carbon dioxide produced

c) determine the number of grams of H_2O produced

d) determine the number of grams of excess reagent left

2. Given the following equation:

$$Al_2(SO_3)_3 + 6\ NaOH \text{ ------> } 3\ Na_2SO_3 + 2\ Al(OH)_3$$

a) If 10.0 g of $Al_2(SO_3)_3$ is reacted with 10.0 g of NaOH, determine the limiting reagent

b) Determine the number of moles of $Al(OH)_3$ produced

c) Determine the number of grams of Na_2SO_3 produced

d) Determine the number of grams of excess reagent left over in the reaction

3. Given the following equation:

$$Al_2O_3 + Fe \text{ ------> } Fe_3O_4 + Al$$

a) If 25.4 g of Al_2O_3 is reacted with 10.2 g of Fe, determine the limiting reagent

b) Determine the number of moles of Al produced

c) Determine the number of grams of Fe_3O_4 produced

d) Determine the number of grams of excess reagent left over in the reaction

Formal Assignment to Submit

Balancing Equations and Simple Stoichiometry

Balance the following equations:

1) ___ N_2 + ___ F_2 → ___ NF_3

2) ___ C_6H_{10} + ___ O_2 → ___ CO_2 + ___ H_2O

3) ___ HBr + ___ $KHCO_3$ → ___ H_2O + ___ KBr + ___ CO_2

4) ___ $GaBr_3$ + ___ Na_2SO_3 → ___ $Ga_2(SO_3)_3$ + ___ NaBr

5) ___ SnO + ___ NF_3 → ___ SnF_2 + ___ N_2O_3

Solve the following stoichiometry grams-grams problems:

6) Using the following equation:

$$2\ NaOH + H_2SO_4 \rightarrow 2\ H_2O + Na_2SO_4$$

How many grams of sodium sulfate will be formed if you start with 200 grams of sodium hydroxide and you have an excess of sulfuric acid?

7) Using the following equation:

$$Pb(SO_4)_2 + 4\ LiNO_3 \rightarrow Pb(NO_3)_4 + 2\ Li_2SO_4$$

How many grams of lithium nitrate will be needed to make 250 grams of lithium sulfate, assuming that you have an adequate amount of lead (IV) sulfate to do the reaction?

Use the following equation to answer questions 8-11:

$$2\ C_6H_{10} + 17\ O_2 \rightarrow 12\ CO_2 + 10\ H_2O$$

8) If I do this reaction with 35 grams of C_6H_{10} and 45 grams of oxygen, how many grams of carbon dioxide will be formed?

9) What is the limiting reagent for problem 6? ____________

10) How much of the excess reagent is left over after the reaction from problem 6 is finished?

11) If 35 grams of carbon dioxide are actually formed from the reaction in problem 6, what is the percent yield of this reaction?