LECTURE TWO

The following topics shall be covered in this Lecture.

- **Atomic and molecular weights.**
- **Percentage compositions, the mole**
- **Chemical equations, reacting quantities.**

Atomic weights

- **Atomic mass of an element is:**
  - **The number of times one atom of the element is as heavy as one atom of hydrogen.**
- **So taking the weight of one hydrogen atom to be 1 amu, all others are compared with the weight of 1-Hydrogen.**
- **In modern times, C-12 is taken as the reference point.**
- **Weight of C-12 is taken to be 12 amu. and all others are referred to this.**

MOLAR MASS

- **This is the mass of one mole of the substance**
- **It is equal to the sum of the atomic masses of the elements that make up the mole.**
- **Calculate the molar mass of the following compounds:**
  - **$Al_2(SO_4)_3$, $Pb(C_2H_3O_2)_2$, $Ca(OH)_2$, Na_2CO_3, $NaHCO_3$**

PERCENTAGE COMPOSTION

- **From the molecular formula of any substance, it is possible to calculate the Percentage composition of each atom in the molecule.**
- **Problems: Calculate the % by wt of each element in:**
- **(i) Magnesium oxide (ii) Ammonium sulphate (iii) Magnesium nitrate.**
- **Calculate the % by wt of water of Crystallisation in: $CuSO_4.5H_2O$, $FeSO_4.H_2O$, $Na_2CO_3.10H_2O$.**

THE MOLE

- **The Quantity of a substance containing as many particles, molecules or formula units as the number of atoms in exactly 12g of ^{12}C.**
- **12g of ^{12}C contains an Avogadro number (N_A) of atoms. $N_A = 6.02 \times 10^{23}$**
- **1 mole of atoms of any element = At. Wt.**
- **1 mole of molecules has a weight = Mol. wt**

Mole (Contd)

- **No of moles n =** $\frac{w}{M}$
- **1 mole of any gas at STP occupies 22.4 L**
- **STP = 0^{o}C and 1 atm Pressure**
- **Problems:**
- **1. Arrange the following in order of increasing mass: (i) 16 molecules of water (ii) 2 atoms of lead (iii) 5.1 $\times 10^{-23}$ mole of helium.**
- **2. What is the mass in grams of a chlorine atom.**
- **3. Calculate the mass in grams of a hydrogen chloride molecule.**

Further Problems:

- 4. Iron pyrite, FeS_2, forms beautiful golden crystals that are know as **"fools gold"**
- **(i)** How many moles of S would be needed to combine with 1.00 mol. Fe to form FeS_2?
- (ii) How many moles of iron are needed to combine with 1.44 mol. S to form FeS_2 ?
- How many moles of S are in 3.00 mol. FeS_2?
- How many moles of FeS_2 are needed to give 3.00 mol. Fe?

1. **Given 0.6 mole of Chlorobenzene, calculate**

   (a) the number of moles of carbon atom in the sample

   (b) The number of molecules of C_6H_5Cl present in the sample

   (c) The number of Hydrogen atoms present in the sample.

2. **Which of the following contains the greatest number of atoms:**

   (i) 0.5 moles of Sulphur dioxide

   (ii) 14 g of Nitrogen

   (iii) 67.2 L of Helium

   (iv) 4 g of Hydrogen

CHEMICAL EQUATIONS

1. **For any reactions, the chemical equation must be balanced, with the formula(e) of reactants to the L and those products to the R.**
2. **Ensure the No of atoms of each kind on both sides are equal i.e. balanced.**

Balance the following equations:

(i) $HCl + Al_2O_3 \rightarrow AlCl_3 + H_2O$

SOLUTION:

$$aHCl + bAl_2O_3 \rightarrow cAlCl_3 + dH_2O$$

H: a = 2d **Cl: a = 3c**

Al: 2b = c **O: 3b = d**

Put c = 1 and solve for others:

b = 1/2 , d = 3/2, a = 3

$$3HCl + \tfrac{1}{2} Al_2O_3 \rightarrow AlCl_3 + 3/2H_2O$$

Clear fractions:

$$6HCl + Al_2O_3 \rightarrow 2AlC_3 + 3H_2O$$

Balance: $H_2SO_4 + Al \rightarrow Al_2(SO_4)_3 + H_2$

$aH_2SO_4 + bAl \rightarrow cAl_2(SO_4)_3 + dH_2$

H: $2a = 2d$ S: $a = 3c$

O: $4a = 12c$ Al $b = 2c$

Put a = 1: and solve for others

$c = 1/3,\ d = 1;\ b = 2/3;\ a = 1$

$\therefore$ $H_2SO_4 + 2/3\ Al \rightarrow 1/3Al_2(SO_4)_3 + H_2$

Clear fractions:

$3H_2SO_4 + 2\ Al \rightarrow Al_2(SO_4)_3 + 3H_2$

Take Home:

Balance the following equations:

(i) $HNO_3 + Cu \rightarrow Cu(NO_3)_2 + N_2O + H_2O$

(ii) $HCl + MnO_2 \rightarrow MnCl_2 + Cl_2 + H_2O$

Balancing of Equations

- **Guide:**
- **1. Balance first the element that occurs in the fewest formulae.**
- **2. Balance last the element that is found in the greatest number of formulae.**
- **e.g. Methane burns in air to give Carbon dioxide and water.**
  - $CH_4 + O_2 \rightarrow CO_2 + H_2O$

Balancing equations

C, H occur in 2 and O_2 occurs in 3 species, so balance C and H first.

$$CH_4 + O_2 \rightarrow CO_2 + 2H_2O$$

Next balance the O_2

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Add the states:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

Try: $C_2H_{10} + O_2 \rightarrow CO_2 + H_2O$

Practice

Balance the following equations:

1. $NH_3(g) + O_2(g) \rightarrow NO(g) + H_2O(g)$
2. $KClO_3\,(s) \rightarrow KCl(s) + O_2\,(g)$
3. $C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$
4. $NH_2(g) + O_2(g) \rightarrow H_2O(g) + N_2\,(g)$
5. $HCl + Al_2O_3 \rightarrow AlCl_3 + H_2O$
6. $H_2SO_4 + Al \rightarrow Al_2(SO_4)_3 + H_2$

REACTING QUANTITIES FROM EQUATION

- 1. Write the balanced equation for the reaction.
- 2. Write the reacting quantities in moles
- 3. Convert the moles to grams as appropriate.
- 4. Calculate the required quantities by simple proportions.

EXERCISE

- 1. 12.25g of potassium chlorate is heated until evolution of oxygen is complete. What is the weight of potassium chloride is produced. Estimate the volume of oxygen evolved.
- 2. 0.92g of a mixture of metallic copper and black copper oxide was heated in a stream of hydrogen until reduction was complete. The residue weighed 0.752g. What was the percentage of copper in the original mixture?
- 3. 8.30g of blue vitrol, $CuSO_4.5H_2O$, was heated to constant weight. How is the mass of the residue?
- 4. 1.547g sample of blue copper(II) sulphate $CuSO_4.xH_2O$, is heated carefully to drive off the water. The white crystals of $CuSO_4$ that are left behind have a mass of 0.989g. How many moles of water were in the original sample?

5. Some blue vitriol $CuSO_4.5H_2O$, was heated to constant weight at 120^o C and then at a higher temperature, with the following result.

Mass of crucible	10.00 g
Mass of Ccrucible + blue vitriol	14.98 g
Mass of crucible + residue (120^o C)	13.54 g
Mass of crucible + residue (at higher Tempt.	13.18 g

What stage of dehydration is reached at each of the two tempts.?

6. A powder contains sodium sulphate anhydrous and decahydrate. On heating to constant weight to produce the pure anhydrous salt. 2.5 g of the powder left 1.60 g of residue. Calculate the percentage by weight of each form of sodium sulphate in the powder.

LECTURE THREE

The following topics will be covered during the cause of this lecture.

1. **Empirical** and **molecular** formulae.
2. **Limiting** reactant and **percentage yield.**

EMPIRICAL/MOLECULAR FORMULAE

Empirical and molecular formulae may be determined from percentage composition.

e.g.

0.184g of a gaseous compound was found to contain 0.12g C, 0.025g H. Find the empirical formula of the compound. If the vapour density of the compound is 37, determine the molecular formula of the compound.

Solution

Follow the following steps:

1. Determine the % composition
2. Determine the number of moles of each element.
3. Determine the mole ratio.

Solution

$$\% \text{ C} = \frac{0.12}{0.184} \times 100 = 65.2\%$$

$$\% \text{ H} = \frac{0.025}{0.184} \times 100 = 13.6\%$$

$$\therefore \% \text{ O} = 100.00 - (65.2 + 13.6) = 21.2\%$$

	C	H	O
No of moles	$\frac{65.2}{12}$	$\frac{13.6}{1}$	$\frac{21.2}{16}$
	5.23	13.6	1.325
Mole ratio	$\frac{5.43}{1.325}$	$\frac{13.6}{1.325}$	$\frac{1.325}{1.325}$
	4.1	10.3	1

Emp./Mol. Formula

Therefore Empirical formula = $C_4H_{10}O$

Since Mol. Wt = 2 x VP = 2 x 37 = 74

Therefore $(C_4H_{10}O)_n = 74$

$74n = 74$

$n = 1$

Hence molecular formula = $C_4H_{10}O$.

Analysis of a compound of C, H, and O gave the following results: C 40%, H 6.71% and O 53.29%. If the molar mass of the compound is 180, determine its molecular formula.

SOLUTION:

No of atoms of C = $\frac{40}{12} \times \frac{180}{100}$ **= 6**

No of atoms of H = $\frac{6.71}{1} \times \frac{180}{100}$ **= 12.08 ≈ 12**

No of atoms of O = $\frac{53.29}{16} \times \frac{180}{100}$ **= 5.995 ≈ 6**

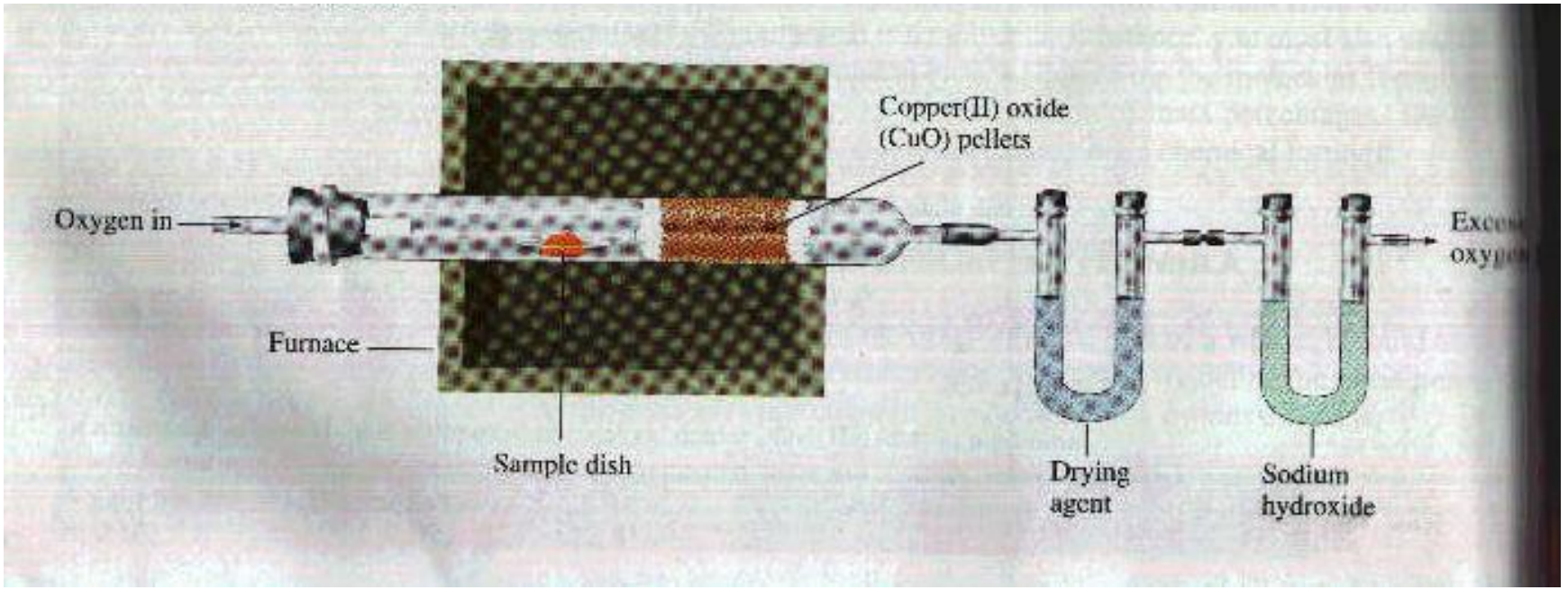
Therefore the molecular Formula = $C_6H_{12}O_6$

ELEMENTAL ANALYSIS

Mainly used for Organic compounds:

1. The organic compound is combusted in air (O_2) and C & H are converted into CO_2 and H_2O respectively.
2. CO_2 is then estimated by passing thro' a U-tube containing NaOH.
3. H_2O is estimated by passing thro' a U-tube containing a drying agent.
4. **The results are then used to establish the Empirical & Molecular formulae.**

Combustion method set up



Example

Citric acid, the substance responsible for the sour taste of lemons, contains only C, H, & O. When 0.50g of citric acid was burnt in air, it produced 0.6871g CO_2 and 0.1874g of H_2O. If the molecular weight of citric acid is 192, determine its molecular formula.

SOLUTION

Step 1: Estimate the mass of C & H in the CO_2 and H_2O produced respectively.

Mass of C = mass of $CO_2 \times \frac{12}{44} = 0.6871 \times \frac{12}{44} = 0.1874gC$

Mass of H_2 = mass of $H_2O \times \frac{2}{18} = 0.1874 \text{ x } \frac{2}{18} = 0.0208gH$

STEP 2: Calculate the % of each element in the compound.

$$\%C = \frac{\text{mass of C}}{\text{mass of sample used}} \times 100 = \frac{0.1874}{0.5} \times 100 = 37.48\%$$

$$\%H = \frac{\text{mass of H}}{\text{mass of sample used}} \times 100 = \frac{0.0208}{0.5} \times 100 = 4.16\%$$

$$\%\ O_2 = [100 - (4.16 + 37.48)] = 58.36\%$$

Step 3:Determine the No of moles

	C	H	O
No of Moles	$\frac{37.48}{12}$ **=3.12**	$\frac{4.16}{1}$ **= 4.16**	$\frac{58.36}{16}$ **= 3.6**
Divide by the least	**1**	**1.33**	**1.15**
x 6	**6**	**7.98 ≈ 8**	**6.9 ≈ 7**

Hence EMP = $C_6H_8O_7$
Now $(C_6H_8O_7)_n$ = 192
$\therefore n = 1$
Hence MF = $C_6H_8O_7$

Limiting Reactant

$$A + B \rightarrow C$$

If A is in excess, the reaction will continue until all B is used up leaving an excess of A.

The extent of the reaction is therefore determined by the amount of B.

Define:

The Limiting reactant is the reactant that is entirely consumed when a reaction goes to completion.

Examples:

(i) In the reaction:

$4KO_2(s) + 2H_2O(l) \rightarrow 4KOH(s) + 3O_2(g)$

A reaction vessel contains 0.15 mol KO_2 and 0.10 mol H_2O.

What is the limiting reagent? How many moles of oxygen can be produced.

Solution:

Find the reactant that would produce the least amount of O_2

4 mol KO_2 produces 3 mol O_2

Hence 0.15 mol will produce $\frac{3}{4} \times 0.15$ = 0.1125 mol

2 mol H_2O produce 3 mol O_2

hence 0.1 mol will produce 3/2 x 0.1 = 0.15 mol

Therefore limiting Reagent is KO_2

Max amount of O_2 that can be produced = 0.1125 mol

Theoretical/Percentage yield

The theoretical yield is the amount that is obtained based on the the stoichiometric equation.

Percentage Yield =

$$\frac{\text{Actual Yield obtained}}{\text{Theoretica l yield}} \times 100$$

Worked Example

Ethyl acetate can be prepared by reacting ethanol (ethyl alcohol) with acetic acid according the equation:

$$CH_3COOH + C_2H_5OH = CH_3COOC_2H_5 + H_2O$$

20g of acetic acid and 11.5g of ethanol are reacted together. Calculate the weight of ethyl acetate expected from this reaction.

SOLUTION

No of moles of acetic acid = 20/60 = 0.33 mol.

No of moles of ethanol initially present = 11/46 = 0.25mol.

Since amount of ethanol is least, it is LIMITING REAGENT

Hence the no of moles of ethyl acetate expected = 0.25 mol.

Mass of ethyl acetate = 0.25 × 88g = 22.0g = Theoretical yield

Solution (Contd)

If the yield obtained = 20.0g

Percentage Yield = $\frac{20}{22}$ = **90.9%**

TELEPHONE FROM HELL

A Nigerian died and went to hell, where he met a Briton and an American. They soon became friends. They all went to Satan and requested to phone home and tell their people that hell was real after all. Satan agreed on the condition that they pay in US$. They agreed.

At the end Satan gave his bill: To the Briton $30.00; To the American US$25; and the Nigerian 30 cents. The American and the Briton protested the low bill given to the Nigerian: Satan replied that the bill to the Nigerian was low because his was a local call.