3.) Calculation Based on Mass- Volume Relationship.

In such calculations, masses of reactant are given & volume of the product is required & Vice Versa.

1 mole of gas occupies 22.4 litre volume at STP, mass of gas can be related to volume according to the following gas Equation:

$$PV = nRT$$

$$PV = \frac{w}{M} RT$$

Example: Calculate the volume of hydrogen liberated at 27°C and 760 mm pressure by treating 1.2g of magnesium with Excesss of Hydrochloric Acid.

Solution: $Mg(s) + 2HCl(g) \longrightarrow MgCl_2(s) + H_2 \uparrow$

1 mole (Mg) — 1 mole (H_2)

24g — 22.4 L at NTP

∴ 24g of Mg liberate hydrogen = 22.4 Litre

1.2g of Mg will liberate hydrogen $= \frac{22.4}{24} \times 1.2 = 1.12$ Litre.

Volume of hydrogen under given condition can be calculated by applying: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ | $V_2 = \frac{760 \times 1.12}{273} \times \frac{300}{760} = 1.23$ litre.

4.) Calculation Based on Volume- Volume Relationship.

These calculation are based on two laws:

(i) Avogadro's Law (ii) Gay- Lussac's Law.

For e.g: $N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$ (Avogadro's Law).

1 mole	3 mole	2 mole.
1 × 22.4 L	3 × 22.4 L	2 × 22.4 L.
1 vol.	3 vol.	2 vol.

Example: What volume of air containing 21% oxygen by volume is required to completely burn 1kg of carbon containing 100% combustible substances?

Solution:

$$C(s) + O_2(g) \longrightarrow CO_2(g)$$

1 mole	1 mole	1 mole.
12g	32g	44g.

∴ 12g of carbon requires 1 mole of O_2 for complete combustion.

∴ 1000g of carbon will require $\frac{1}{12} \times 1000$ mole O_2 = 83.33 mole

∴ Volume of O_2 at NTP = 83.34 × 22.4 Litre = 1866.592 litre

∵ 21 litre of O_2 is present in 100 litre air,

∴ 1866.592 litre of O_2 will be present in $\left(\frac{100}{21} \times 1866.592 \text{ litre}\right)$

= 8888.5 litre.

Example: A mixture of $NaHCO_3$ & Na_2CO_3 weighed 1.0235g. The dissolved mixture was reacted with excess of $Ba(OH)_2$ to form 2.1028 g $BaCO_3$, by the following reactions:

$$Na_2CO_3(s) + Ba(OH)_2 \longrightarrow BaCO_3 + 2NaOH.$$

$$NaHCO_3 + Ba(OH)_2 \longrightarrow BaCO_3 + NaOH + H_2O.$$

What was the percentage of $NaHCO_3$ in the original mixture?

Solution: let x g of $NaHCO_3$ be present in the mixture

mass of Na_2CO_3 in the mixture = $(1.0235 - x)$ g.

Number of moles of $NaHCO_3$ = $\left(\frac{x}{84}\right)$.

Number of moles of Na_2CO_3 = $\left(\frac{1.0235 - x}{106}\right)$.

Numbers of moles of $BaCO_3$ = (No. of moles of Na_2CO_3) + (No. of moles of $NaHCO_3$)

$$\left(\frac{2.1028}{197}\right) = \left(\frac{x}{84}\right) + \left(\frac{1.0235 - x}{106}\right)$$

$x = 0.4122 g.$

Amount of $NaHCO_3$ = 0.4122g.

Percentage of $NaHCO_3$ = $\frac{0.4122g}{1.0235} \times 100 = 40.27\%$.

<u>Example:</u> A mixture of ethane & ethene occupies 40 litre at 1 atm and at 400K. The mixture react completely with 130g of O_2 to produce CO_2 & H_2O. Assuming ideal gas behaviour, calculate the mole fraction of C_2H_6 & C_2H_4 in the mixture?

<u>Solution:</u> Volume of mixture at NTP: $\frac{V_1}{T_1} = \frac{V_2}{T_2}$.

$$V_2 = \frac{40 \times 273}{400} = 27.3 \text{ litre.}$$

let the volume of ethane = x Litre.

Volume of ethene = (27.3−x) litre.

Balanced equation: $C_2H_6 + \frac{7}{2}O_2 \longrightarrow 2CO_2 + 3H_2O$

1 vol. $\frac{7}{2}$ vol. 2 vol. 3 vol.

$C_2H_4 + 3O_2 \longrightarrow 2CO_2 + 2H_2O$

1 vol. 3 vol. 2 vol. 2 vol.

Total volume of oxygen required for complete combustion of the mixture is; $\left[\frac{7}{2}x + (27.3 - x) \times 3\right]$ litre

$$\text{Mass of oxygen} = \left[\frac{7x + (27.3 - x) \times 6}{2}\right] \times \frac{32}{22.4}$$

$$130 = (x + 163.8) \times \frac{16}{22.4}$$

$$x = 18.2$$

Hence, Mole fraction of ethane = $\frac{18.2}{27.3} \times 100 = 66.66$.

Mole fraction of ethene = 33.34.

Example: 3.6g of sodium chloride & potassium chloride is dissolved in water. The solution is treated with excess of silver nitrate solution. 7.74g of silver chloride is obtained. Find out the percentage of NaCl & KCl in the mixture.

Solution: The balanced equation b/w NaCl & $AgNO_3$ is.

$$NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$$

1 mole ... 1 mole

58.5g ... 143.5g

Let xg of NaCl be present in the mixture,

58.5g NaCl produce = 143.5g AgCl.

xg of NaCl will produce $= \frac{143.5}{58.5} \times x$g AgCl.

The balanced chemical equation between KCl & $AgNO_3$ is:

$$KCl + AgNO_3 \rightarrow AgCl + KNO_3$$

1 mole ... 1 mole

74.5g ... 143.5g

KCl present in the mixture = $(3.6 - x)$ g.

74.5g of KCl produce = 143.5g of AgCl.

$(3.6-x)$ g of KCl will produce $= \frac{143.5}{74.5} \times (3.6-x)$ g of AgCl.

Thus, $\frac{143.5}{58.5}x + \frac{143.5}{74.5}(3.6-x) = 7.74$

$x = 1.54$

% of NaCl $= \frac{1.54}{3.60} \times 100 = 42.7\%$

% of KCl $= \left(\frac{3.6-1.54}{3.6}\right) \times 100 = 57.3\%$

Example: A 1g sample of $KClO_3$ was heated under such condition that a part of it was decomposed according to the equation:

$$2KClO_3 \rightarrow 2KCl + 3O_2 \quad \text{---- (i)}$$

and the remaining underwent change according to the equation,

$4KClO_3 \longrightarrow 3KClO_4 + KCl$ ----- (ii)

If the amount of oxygen evolved was 146.8 mL at STP, calculate the percentage by mass of $KClO_4$ in the residue.

Solution: $2KClO_3 \longrightarrow 2KCl + 3O_2$.

245g 149g 67.2 Litre.

67.2 Litre of oxygen evolved from 245g of $KClO_3$.

0.1468 Litre of oxygen will be evolved $= \left(\frac{245}{67.2} \times 0.1468\right)$

$= 0.535g$ of $KClO_3$.

Hence, $KClO_3$ left for the equation (ii) reaction,

$(1 - 0.535)g = 0.464g$.

245g of $KClO_3$ will yield $KCl = 149g$.

0.5352g of $KClO_3$ will yield $KCl = \left(\frac{149}{245} \times 0.535g\right) = 0.325g$

consider eq (ii)

$4KClO_3 \longrightarrow 3KClO_4 + KCl$.

490g 415.5g 74.5g

490g of $KClO_3$ yield = 415.5g of $KClO_4$.

0.4648 g of $KClO_3$ will yield $= \left(\frac{415.5g}{490g} \times 0.4648\right) = 0.394g$ of $KClO_4$.

490g of $KClO_3$ yield = 74.5g of KCl

0.4648g of $KClO_3$ will yield $= \left(\frac{74.5}{490} \times 0.4648\right) = 0.0707g$ of KCl.

Total mass of the residue $= (0.3254 + 0.3941 + 0.0707)$

$= 0.7902g$.

$\% \; KClO_4 = \left(\frac{0.3941}{0.7902} \times 100\right) = 49.8$.

Example: A mixture of FeO & Fe_3O_4 when heated in air to a constant weight gains 5% in its mass. Find the composition of the initial mixture.

Solution: Let the % FeO in the mixture = x g.

% Fe_3O_4 in the mixture = $(100-x)$.

FeO on heating is converted in Fe_2O_3.

$$4FeO + O_2 \rightarrow 2Fe_2O_3$$
288g 320g

288g of FeO yield = 320g of Fe_2O_3.

x g of FeO will yield = $\frac{320}{288} x$ g of Fe_2O_3.

$$2Fe_3O_4 + \frac{1}{2}O_2 \rightarrow 3Fe_2O_3$$
464g 480g

464g of Fe_3O_4 yield = 480g of Fe_2O_3.

$(100-x)$g of Fe_2O_3 will yield = $\frac{480g}{464g}(100-x)$ of Fe_2O_3.

Total Fe_2O_3 = $\frac{320}{288}x + \frac{480}{464}(100-x)$

According to the question, 5% of increase in weight;

$$\frac{320}{288}x + \frac{480}{464}(100-x) = 105.$$

$x = 20.2$.

% FeO = 20.2 % % Fe_3O_4 = 79.8 %.

Example: A mixture in which the mole ratio of H_2 & O_2 is 2:1 is used to prepare water by the reaction:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g).$$

The total pressure of the container is 0.8 atm at 20°C before the reaction. Determine the final pressure at 120°C after the reaction, assuming 80% yield of water.

Solution: The given reaction is :-

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$

	$2H_2(g)$	$O_2(g)$	$2H_2O(g)$
Initial mole	$2n$	n	0
Final mole	$(2n-2x)$	$(n-x)$	$2x$

% yield = 80 $\left| \frac{2x}{2n} \times 100 = 80 \right|$ $x = 0.8n$

After the reaction,

Number of mole of $H_2 = (2n - 2 \times 0.8n) = 0.4n$.

Number of mole of $O_2 = 0.2n$.

Number of mole of $H_2O = 1.6n$.

Total moles $= (0.4n + 0.2n + 1.6n) = 2.2n$

Initial state : $PV = nRT$

$$0.8 \times V = 3n \times R \times 293 \quad \text{——— (1)}$$

After the reaction, $P \times V = 2.2n \times R \times 393$ ——— (2)

From (1) & (2) $\quad P = 0.787$ atm.

Exercise:

(1) Calculate the weight of lime (CaO) that can be obtained by heating 200kg of limestone which is 93% pure. [Ans- 104.16 kg]

(2.) Calculate the volume of air containing 21% by volume of oxygen at NTP required to convert 294 mL of SO_2 into SO_3 under the same condition. [Ans. 700mL]

(3.) What weight of AgCl will be precipitated when a solution containing 4.77g of NaCl is added to a solution of 5.77g of $AgNO_3$. [Ans: 4.87g]

(4) Equal weight of Hg & iodine are allowed to react completly to form a mixture of mercurous iodide & mercuric iodide. calculate the ratio of mass of mercurous iodide & mercuric iodide formed. [Ans. 0.513 : 1]

(5) A mixture of calcium & magnesium carbonate weighing 1.4g was strongly heated untill no further loss of weight was percieved. The residue weighed 0.76g. What percentage of $MgCO_3$ was present in the mixture? [Ans: 20.45%]

Principle of Atom Conservation (POAC)

The principle of conservation of mass, expressed in the concept of atomic theory, means the conservation of atom. And if atoms are conserved, moles of atoms shall also be conserved. This is known as Principle of Atom conservation (POAC).

$$KClO_3 \longrightarrow KCl(s) + O_2(g)$$ [No balancing of equation required].

Apply the POAC for K atoms.

Moles of K atom in reactant = Moles of K atoms in products

Mole of K atom in $KClO_3$ = moles of K atoms in KCl.

Since 1 mole of $KClO_3$ contains 1 mole of K, similarly 1 mole of KCl contain 1 mole of K.

Moles of K atom in $KClO_3$ = 1 × moles of $KClO_3$.

& Mole of K atom in KCl = 1 × mole of KCl.

Moles of $KClO_3$ = moles of KCl.

$$\frac{\text{wt. of } KClO_3 \text{ in (g)}}{\text{Mol. wt. of } KClO_3} = \frac{\text{wt. of KCl}}{\text{Molecular wt. of KCl}}$$

Similarly, applying the principle of atom conservation for O atoms,

Moles of O in $KClO_3$ = Mole of O in O_2.

Moles of O in $KClO_3$ = 3 moles of $KClO_3$.

Moles of O in O_2 = 2 moles of O_2.

3 × moles of $KClO_3$ = 2 × moles of O_2.

$$3 \times \frac{\text{wt. of } KClO_3}{\text{mol. wt. of } KClO_3} = 2 \times \frac{\text{Vol. of } O_2 \text{ at NTP}}{\text{standard molar volume}}$$

Example: 27.6 g of K_2CO_3 was treated by a series of reagent so as to convert all its carbon to $K_2Zn_3[Fe(CN)_6]_2$. Calculate the weight of the product.

Solution: $K_2CO_3 \xrightarrow[\text{steps}]{\text{Several}} K_2Zn_3[Fe(CN)_6]_2$.

Since Carbon atoms are conserved, applying POAC for Carbon.

Moles of C atom in K_2CO_3 = Moles of carbon atom in $K_2Zn_3[Fe(CN)_6]_2$

1 mole of K_2CO_3 = 12 moles of $K_2Zn_3[Fe(CN)_6]_2$.

$$\frac{\text{wt. of } K_2CO_3}{\text{Mol. wt. of } K_2CO_3} = 12 \times \frac{\text{wt. of } K_2Zn_3[Fe(CN)_6]_2}{\text{mol. wt. of } K_2Zn_3[Fe(CN)_6]_2}$$

$$\frac{27.6g}{138g} = 12 \times \frac{\text{wt. of } K_2Zn_3[Fe(CN)_6]_2}{698}$$

$$\text{wt. of } K_2Zn_3[Fe(CN)_6]_2 = \frac{27.6}{138} \times \frac{698}{12} = 11.6g.$$

Example: 10cc of H_2O_2 solution when reacted with KI solution produced 0.5g of iodine. Calculate the percentage purity of H_2O_2.

Solution: $H_2O_2 + KI \longrightarrow KOH + I_2$.

POAC for H atom,

moles of H in H_2O_2 = mole of H in KOH.

$2 \times$ moles of H_2O_2 = 1 moles of KOH ——— (1.)

POAC for K atom,

Mole of K in KI = mole of K in KOH.

1 mole of KI = 1 moles of KOH ——— (2.)

= $2 \times$ moles of H_2O_2. ——— (3.)

POAC for Iodine atoms

moles of I atom in KI = moles of I atom in I_2.

$1 \times$ moles of KI = $2 \times$ moles of I_2.

moles of I_2 = $\frac{1}{2} \times$ moles of KI.

= $\frac{1}{2} \times (2 \text{ moles of } H_2O_2)$.

$$\frac{\text{wt. of } I_2}{\text{mol. wt. of } I_2} = \frac{\text{wt. of } H_2O_2}{\text{mol. wt. of } H_2O_2}$$

$$\frac{0.5}{254} = \frac{x}{34} \quad \Big| \quad x = \frac{34 \times 0.5}{254} = 0.0669\,g.$$

$$\%\ H_2O_2 = \frac{0.0669}{10} \times 100 = 0.669\%.$$

Example: 1 g mixture of cuprous oxide & cupric oxide was quantitatively reduced to 0.839 g of metallic copper. What was the weight of cupric oxide in the original sample.

Solution: Let the weight of CuO be x g. The weight of Cu_2O will be (1−x) g.

POAC for Cu atom.

moles of Cu in CuO + moles of Cu in Cu_2O = moles of Cu in the product.

1 × moles of CuO + 2 × moles of Cu_2O = moles of Cu.

$$\frac{x}{79.5} + 2 \times \frac{(1-x)}{143} = \frac{0.839}{63.5}$$

$$x = 0.55\,g.$$

Exercise:

1.) What weight of CO is required to form $Re_2(CO)_{10}$ from 2.5 g of Re_2O_7 according to the unbalanced reaction:

$$Re_2O_7 + CO \longrightarrow Re_2(CO)_{10} + CO_2.$$ [Ans: 2.46 g]

2.) From the following reaction: $2CoF_2 + F_2 \rightarrow 2CoF_3$.

$$(CH_2)_n + 4n\,CoF_3 \longrightarrow (CF_2)_n + 2n\,HF + 4n\,CoF_2.$$

Calculate how much F_2 will be consumed to produce 1 kg of $(CF_2)_n$.

[Ans ÷ 1.52 kg]

3.) 25.4 g of iodine & 14.2 g of chlorine are made to react completely to yield a mixture of ICl & ICl_3. Calculate the number of moles of ICl & ICl_3 formed.

Ans ÷ (0.1 mole, 0.1 mole)