Stoichiometry

Stoichiometry is the calculation of quantities of reactant and products involved in a chemical reaction. It is based on chemical equation & on the relationship between mass & moles.

A chemical equation can be interpreted as follows:

$N_2(g) + 3H_2(g) \longrightarrow 2NH_3(g)$. (Molecular interpretation)

1 molecule of N_2 + 3 molecule of H_2 $\longrightarrow$ 2 molecule of NH_3

1 mole of N_2 + 3 mole of H_2 $\longrightarrow$ 2 mole of NH_3 (Mole interpretation).

28g of $N_2(g)$ + 6g of H_2 $\longrightarrow$ 34g of NH_3 (Mass interpretation)

1 vol. of $N_2(g)$ + 3 vol. of H_2 $\longrightarrow$ 2 vol. of NH_3 (volume interpretation).

Calculation based on chemical equation can be divided as:

1. Calculation based on mole-mole relationship.
2. Calculation based on mass-mass relationship.
3. Calculation based on mass-volume relationship.
4. Calculation based on volume-volume relationship.

1) Calculation based on mole-mole relationship.

In such calculation, number of moles of reactants are given & those of products are required. Conversely, if number of moles of products are given, then number of moles of reactant are required.

Example. 1: Oxygen is prepared by catalytic decomposition of Potassium chlorate ($KClO_3$). Decomposition of potassium chlorate gives potassium chloride (KCl) & oxygen (O_2). How

many moles & how many gram of $KClO_3$ are required to produce 2.4 mole O_2 ?

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

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

3 moles of O_2 formed by 2 moles of $KClO_3$.

∴ 2.4 mole of O_2 formed by $\left(\frac{2}{3} \times 2.4\right)$ moles of $KClO_3$.

= 1.6 moles of $KClO_3$.

∴ Mass of $KClO_3$ = number of moles × molar mass

= 1.6 × 122.5

= 196 g.

2.) Calculation based on mass-mass relationship.

In making necessary calculations, following steps are followed:

a.) Write down balanced chemical equation.

b.) Write down theoretical amount of reactants & products involved in the reaction.

c.) calculate the unknown amount of substance using unitary method.

Example: 2: Chlorine is prepared in the laboratory by treating manganese dioxide (MnO_2) with aqueous hydrochloric acid according to the reaction:

$$MnO_2(s) + 4HCl(aq.) \longrightarrow MnCl_2(s) + Cl_2(g)\uparrow + 2H_2O(aq)$$

How many gram of HCl will react with 5g of MnO_2?

Solution: 1 mole of MnO_2 react with 4 mole of HCl

87g of MnO_2 react with 146g of HCl.

5g of MnO_2 react with = $\frac{146g}{87g} \times 5 = 8.39g$ of HCl.

Example:3: How many killogram of pure H_2SO_4 could be obtained from 1kg of pyrites (FeS_2) according to the following reaction:

$$4\,FeS_2 + 11O_2 \longrightarrow 2\,Fe_2O_3 + 8\,SO_2.$$

$$2SO_2 + O_2 \longrightarrow 2SO_3$$

$$SO_3 + H_2O \longrightarrow H_2SO_4.$$

Soln: Final balanced chemical Equation:

$$4\,FeS_2 + 15\,O_2 + 8\,H_2O \longrightarrow 2\,Fe_2O_3 + 8\,H_2SO_4.$$

4 mole of FeS_2 yield 8 mole of H_2SO_4.

$4 \times 120g$ of FeS_2 = $8 \times 98g$ of H_2SO_4.

1000 g of FeS_2 will yield $H_2SO_4 = \left(\frac{8 \times 98}{4 \times 120} \times 1000g\right)$

$= 1.63$ Kg.

Limiting Reagent:

Limiting Reagent or reactant is the reactant that is entirely consumed when a reaction goes to completion. Othe reactants which are not completly consumed in the reaction are called excess reagent.

Example:4. If 10g of $CaCO_3$ is treated with 10g of HCl, how many grams of CO_2 can be generated according to the following reaction:

$$CaCO_3(s) + 2HCl(aq.) \longrightarrow CaCl_2(aq.) + H_2O(l) + CO_2(g)$$

Solution: $CaCO_3(s) + 2HCl(aq.) \longrightarrow CaCl_2(aq.) + H_2O(l) + CO_2(g)$

1mole	1mole		1mole
100g	73g		44g

100g of $CaCO_3$ gives 44g of CO_2

20g of $CaCO_3$ will give $\frac{44}{100} \times 20g = 8.8g$ of CO_2.

Let HCl be completely consumed,

73g of HCl gives 44g of CO_2.

20g HCl will give $\frac{44g}{73} \times 20g = 12.054g$ of CO_2.

Since $CaCO_3$ give least amount of product CO_2. Hence, $CaCO_3$ is limiting reagent. Amount of CO_2 formed will be 8.8g.

Example: 5: 100g sample of calcium carbonate is reacted with 70g of orthophosphoric acid. calculate-

(a.) The number of gram of calcium phosphate that could be produced.

(b.) The number of gram of excess reagent that will remain unreacted.

<u>Solution:</u> $3\,CaCO_3(s) + 2H_3PO_4 \longrightarrow Ca_3(PO_4)_2 + 3\,CO_2 + 3H_2O$

Mole:	3 mole	2 mole	1 mole
Mass:	300g	196g	310g

300g of $CaCO_3$ produce $Ca_3(PO_4)_2 = 310g$

100g of $CaCO_3$ would produce:

$$Ca_3(PO_4)_2 = \frac{310}{300} \times 100 = 103g = 0.33 mol$$

196g of H_3PO_4 produce $Ca_3(PO_4)_2 = 310g$ or 1 mole

70g of H_3PO_4 would produce $Ca_3(PO_4)_2$.

$$= \frac{310}{196} \times 70 = 110.7g \text{ or } 0.356 \text{ mol}$$

The above value suggest that $CaCO_3$ is the limiting agent. Hence calcium phosphate formed is 103g or 0.33 mole.

b.) For producing 103g of $Ca_3(PO_4)_2$, H_3PO_4 required will be,

$$= \frac{196}{310} \times 103 = 65.12g.$$

Mass of remaining H_3PO_4 $= (70 - 65.12) = 4.88g.$

Calculation involving Percent yield.

$$\text{Percent yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100.$$

The amount of Product that is actually obtained is known as actual yield.

Example 6: For the reaction:

$$CaO(s) + 2HCl(aq.) \longrightarrow CaCl_2(s) + H_2O$$

1.23g of CaO is reacted with excess of hydrochloric acid & 1.85g of $CaCl_2$ is formed. What is the percent yield?

<u>solution:</u> The balanced equation is:

$$CaO + 2HCl \longrightarrow CaCl_2 + H_2O.$$

56g 73g 111g.

56g of CaO produce $CaCl_2$ = 111g

1.23g of CaO produce $CaCl_2 = \frac{111g}{56g} \times 1.23g.$

$= 2.43g$ of $CaCl_2$.

Thus theoretical yield $= 2.43g$.

Actual yield $= 1.85g$.

Percent yield $= \frac{1.85}{2.43} \times 100 = 76.1\%$

Example: 8. Magnetite Fe_3O_4, can be converted into metallic iron by heating with carbon monoxide can be represented by this equation:

$$Fe_3O_4 + 4CO \longrightarrow 3Fe + 4CO_2.$$

How many kilogram of Fe_3O_4 must be processed in this way to obtain 5 kg of iron, if the process is 85% efficient?

Solution: 1 mole of Fe_3O_4 (232 g) = 3 mole Fe (168 g)

Amount of Fe_3O_4 required for 5 kg iron $= \frac{232}{168} \times 5$ kg

$= 6.904$ kg.

Since, the efficiency of the reaction is 85%, hence the actual required amount of Fe_3O_4 will be,

$$= \frac{100 \times 6.904}{85} \text{ kg} = 8.12 \text{ kg}.$$

Analysis of the mixture:

In such problem, one of the component is supposed to be kg & the other will be the difference from total. Balanced chemical reaction for the reaction of both component are now written & the total amount the common product produced by the component of the mixture is calculated. It is equated with the data given & the unknown factor are, thus worked out.

Example: 9. A solid mixture (5g) containing of lead nitrate & sodium nitrate was below 600°C, untill the mass of the residue was constant. If the loss in mass is 28%. Find the amount of lead nitrate & sodium nitrate in mixture?

Solution: Let the amount of $NaNO_3$ in the mixture be xg. The amount of $Pb(NO_3)_2$ in the mixture $= (5-x)$g.

$$2\,NaNO_3 \longrightarrow 2\,NaNO_2 + O_2(g)$$

2×85g $\qquad$ 32g.

$$2\,Pb(NO_3)_2 \longrightarrow 2\,PbO + 4NO_2 + O_2.$$

2×331g $= 662$g $\qquad$ $\underbrace{4 \times 46\text{g} \quad 32\text{g}}_{216\text{g}}$

170g of $NaNO_3$ evolve oxygen = 32g.

xg of $NaNO_3$ evolve $= \frac{32}{170} \times x$g

662g of $Pb(NO_3)_2$ evolve gases = 216g.

$(50-x)$g of $Pb(NO_3)_2$ evolve gases $= \frac{216\text{g}}{662\text{g}} \times (50-x)$g

Total loss $= \left(\frac{32}{170} \times x\text{g} + \frac{216}{662} \times (5-x)\right)$

loss give in the problem $= \frac{28}{100} \times 5\text{g} = 1.4$g.

$$\frac{32x}{170} + \frac{216}{662}(5-x) = 1.4.$$

On solving, $x = 1.676$g.

Mass of $NaNO_3 = 1.676$g.

Mass of $Pb(NO_3)_2 = (5 - 1.676)$g $= 3.324$g.

Example: 10: A solid mixture (5g) consisting of lead nitrate & sodium nitrate was heated below 600°C until the weight of the residue is constant. If the loss in weight is 28%, find the amount of lead nitrate & sodium nitrate in the mixture.

<u>Solution</u>: Loss of weight is due to formation of NO_2 & O_2 gases (weight loss $= \frac{5}{100} \times 28 = 1.4g$)

$$Pb(NO_3)_2 \longrightarrow PbO + \underbrace{NO_2 + O_2}_{y g}$$

$x g$ $\quad (x-y) g$

$$NaNO_3 \longrightarrow NaNO_2 + \frac{1}{2} O_2$$

$(5-x)$ $\quad (3.6-x+y)$ $\quad (1.4-y)$

Number of moles of $Pb(NO_3)_2$ = Number of moles of PbO.

$$\frac{x}{331} = \frac{x-y}{223} \quad \text{——— (i)}$$

Number of moles of $NaNO_3$ = No. of moles of $NaNO_2$.

$$\frac{(5-x)}{85} = \frac{(3.6-x+y)}{69} \quad \text{——— (2)}$$

solving eq (1) & (2)

Mass of $Pb(NO_3)_2 = x = 3.32646 g$.

Mass of $NaNO_3 = (5-x) = 1.6754 g$.

Assignment

Q.1 1 gm sample of $KClO_3$ was heated under such conditions that a part of it decomposed according to the equation(1) $2KClO_3 \longrightarrow 2\,KCl + 3O_2$
and remaining underwent change according to the equation.
(2) $4KClO_3 \longrightarrow 3\,KClO_4 + KCl$
If the amount of O_2 evolved was 146.8 ml at S.T.P., calculate the % by weight of $KClO_4$ in the residue.

Q.2 A sample of calcium carbonate contains impurities which do not react with a mineral acid. When 2 grams of the sample were reacted with the mineral acid, 375 ml of carbon dioxide were obtained at 27°C and 760 mm pressure. Calculate the % purity of the sample of $CaCO_3$?

Q.3 One gram of an alloy of aluminium and magnesium when heated with excess of dil. HCl forms magnesium chloride, aluminium chloride and hydrogen. The evolved hydrogen collected over mercury at 0°C has a volume of 1.2 litres at 0.92 atm pressure. Calculate the composition of the alloy.

Q.4 A sample containing only $CaCO_3$ and $MgCO_3$ is ignited to CaO and MgO. The mixture of oxides produced weight exactly half as much as the original sample. Calculate the percentages of $CaCO_3$ and $MgCO_3$ in the sample.

Q.5 Determine the percentage composition of a mixture of anhydrous sodium carbonate and sodium bicarbonate from the following data:
wt. of the mixture taken = 2g
Loss in weight on heating = 0.124 g.

Q.6 A 10 g sample of a mixture of calcium chloride and sodium chloride is treated with Na_2CO_3 to precipitate calcium as calcium carbonate. This $CaCO_3$ is heated to convert all the calcium to CaO and the final mass of CaO is 1.62g. Calculate % by mass of NaCl in the original mixture.

Q.7 In a gravimetric determination of P an aqueous solution of NaH_2PO_4 is treated with a mixture of ammonium and magnesium ions to precipitate magnesium ammonium phosphate $Mg(NH_4)PO_4 \cdot 6H_2O$. This is heated and decomposed to magnesium pyrophosphate, $Mg_2P_2O_7$ which is weighed. A solution of NaH_2PO_4 yielded 1.054 g of $Mg_2P_2O_7$. What weight of NaH_2PO_4 was present originally ?

Q.8 By the reaction of carbon and oxygen, a mixture of CO and CO_2 is obtained. What is the composition of the mixture obtained when 20 grams of O_2 reacts with 12 grams of carbon ?

Q.9 A mixture of nitrogen and hydrogen. In the ratio of one mole of nitrogen to three moles of hydrogen, was partially converted into NH_3 so that the final product was a mixture of all these three gases. The mixture was to have a density of 0.497 g per litre at 25°C and 1.00 atm. What would be the mass of gas in 22.4 litres at S.T.P? Calculate the % composition of this gaseous mixture by volume.

Q.10 Direct reaction of iodine (I_2) and chlorine (Cl_2) produces an iodine chloride, I_xCI_y , a bright yellow solid. If you completely used up 0.508 g of iodine and produced 0.934 g of I_xCI_y, what is the empirical formula of the compound? Later experiment showed the molar mass, of I_xCI_y was 467 g/mol. What is the molecular formnula of the compound ? (I = 127)

Q.11 Equal weights of mercury and I_2 are allowed to react completely to form a mixture of mercurous and mercuric iodide leaving none of the reactants. Calculate the ratio of the wts of Hg_2I_2 and HgI_2 formed.

Q.12 Titanium, which is used to make air plane engines and frames, can be obtained from titanium tetrachloride, which in turn is obtained from titanium oxide by the following process :

$$3\ TiO_2(s) + 4C\ (s) + 6Cl_2\ (g) \longrightarrow 3TiCl_4(g) + 2CO_2(g) + 2CO\ (g)$$

A vessel contains 4.15 g TiO_2, 5.67 g C and; 6.78 g Cl_2, suppose the reaction goes to completion as written, how many gram of $TiCl_4$ can be produced ? (Ti = 48)

Q.13 A chemist wants to prepare diborane by the reaction

$$6\ LiH + 8BF_3 \longrightarrow 6Li\ BF_4 + B_2H_6$$

If he starts with 2.0 moles each of LiH & BF_3. How many moles of B_2H_6 can be prepared.

Q.14 When you see the tip of a match fire, the chemical reaction is likely to be

$$P_4S_3 + 8O_2 \longrightarrow P_4O_{10} + 3SO_2$$

What is the minimum amount of P_4S_3 that would have to be burned to produce at least 1.0 g of P_4O_{10} and at least 1.0 g of SO_2

Answer Key

Q.1 49.9%

Q.2 76.15% Q.3 Al = 0.546 g; Mg = 0.454 g Q.4 28.4%, 71.6%

Q.5 %$NaHCO_3$ = 16.8, % Na_2CO_3= 83.2 Q.6 67.9% Q.7 1.14 gm

Q.8 CO : CO_2 = 21 : 11 Q.9 12.15 gm; 14.28%, H_2 42.86%, NH_3 42.86%

Q.10 ICl_3, I_2Cl_6 Q.11 0.532 : 1 Q.12 9.063 gm Q.13 0.250

Q.14 1.14 g