

STOICHIOMETRIC CALCULATIONS

Section - 2

In this section, we will discuss the problems based on balanced chemical equations and application of mole concept.

The analysis of a chemical reaction is generally carried out in the form of mass of reacting species taking part in a given reaction (**gravimetric analysis**) or in terms of concentrations of reacting species taking part in a given reaction (**volumetric analysis**).

In Gravimetric Analysis, we generally analyse reactions such as : decomposition of compounds under heat to produce a residue and a gas, or displacement reactions, action of acids on metals, or simple balanced chemical equations involving Weight (solid) – Volume (gas) relationships.

In Volumetric Analysis, we generally analyse Neutralisation and Redox Titrations involving aqueous solutions in general.

Neutralisation :

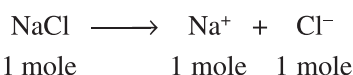
A reaction in which an acid (or a base) completely reacts with a base (or an acid) to form salt and water is called as **Neutralisation**. If HA be the acid, BOH be the base and BA be the salt, then neutralisation reaction can be represented as follows :

**Redox Reactions :**

A reaction in which both oxidation and reduction takes place simultaneously is called as **Redox reaction**. A redox reaction always involves a pair of **oxidising agent** and a **reducing agent**.

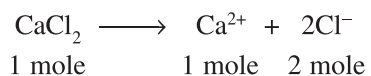
Note : We will deal with Redox Reactions in the next chapter.

Before we move on to study the balanced chemical equations, let us first analyse meaning of some terms.

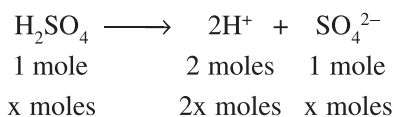
Moles of NaCl :

⇒ 1 mole of NaCl contains 1 mole of Na^+ (ion) and 1 mole of Cl^- ion

⇒ 2 moles of NaCl contains 2 moles of Na^+ ion and 2 moles of Cl^- ion

Moles of CaCl_2 :

⇒ 4 moles 4 moles 8 moles

x-moles of H_2SO_4 :

Application of Mole Concept on Balanced Chemical Equations :

Consider a general balanced chemical reaction or equation :



where A and B are reactants; C and D are products; m, n, p, q are the stoichiometric coefficients.

The above balanced reaction is analysed as :

m moles of A react with n moles of B to produce p moles of C plus q moles of D.

This can be represented (written) as :

**Illustrating the mole concept :**

***What weight of KCl (Potassium Chloride) will be formed on heating 12.25 gm of KClO_3 ?
Also calculate weight of O_2 will be liberated.***

First write a balanced chemical equation for decomposition of KClO_3 .



From Stoichiometry, we have :



$$\text{moles of } \text{KClO}_3 = \frac{12.25}{122.5} = 0.1$$

$$\left[\begin{array}{l} M_0(\text{KClO}_3) = 122.5 \\ \text{moles} = \frac{\text{g}}{M_0} \\ M_0(\text{KCl}) = 74.5 \end{array} \right]$$

Now, $2 \text{ moles of } \text{KClO}_3 \equiv 2 \text{ moles of } \text{KCl}$

$\Rightarrow 0.1 \text{ moles of } \text{KClO}_3 \equiv 0.1 \text{ moles of } \text{KCl}$

$$\equiv 0.1 \times 74.5 \text{ gm of } \text{KCl} \quad [g = \text{moles} \times M_0]$$

$\equiv 7.45 \text{ gms of } \text{KCl} \text{ are formed.}$

Similarly, $2 \text{ moles of } \text{KClO}_3 \equiv 3 \text{ moles of } \text{O}_2$

$$\begin{aligned} \Rightarrow 0.1 \text{ moles of } \text{KClO}_3 &\equiv \frac{3}{2} \times 0.1 \text{ moles of } \text{O}_2 \equiv \frac{3}{2} \times 0.1 \times 32 \text{ gms of } \text{O}_2 \\ &= 4.8 \text{ gm of } \text{O}_2. \end{aligned}$$

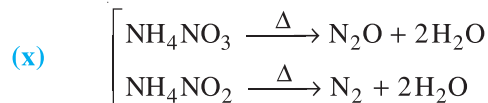
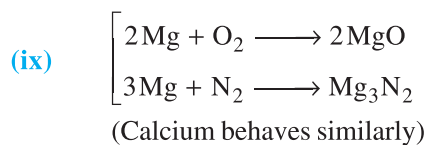
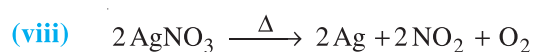
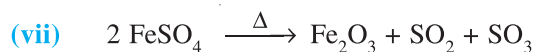
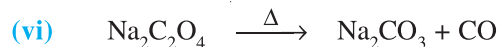
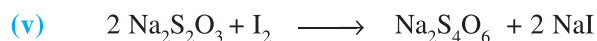
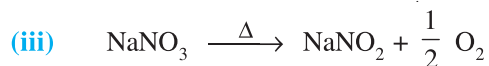
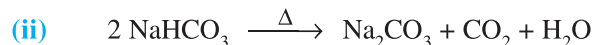
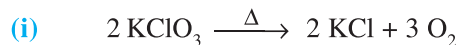
1. Some Important Anions used in Stoichiometry :

X^- (halides)	Cl^- : Chloride,	Br^- : Bromide,	I^- : Iodide
O^{2-}	Oxide	S^{2-}	Sulphide
N^{3-}	Nitride	P^{3-}	Phosphide
CO_3^{2-}	Carbonate	HCO_3^-	Bicarbonate
NO_3^-	Nitrate	NO_2^-	Nitrite
SO_4^{2-}	Sulphate	HSO_4^-	Bisulphate
SO_3^{2-}	Sulphite	PO_4^{3-}	Phosphate
$C_2O_4^{2-}$	Oxalate	$HC_2O_4^-$	Bioxalate
$S_2O_3^{2-}$	Thiosulphate	$S_4O_6^{2-}$	Tetrathionate
ClO_3^- : Chlorate ; BrO_3^- : Bromate ; IO_3^- : Iodate			
MnO_4^-	Permanganate	$Cr_2O_7^{2-}$	Dichromate

2. Action of Heat on Some Important Compounds :

	Alkali Metals	Alkaline Earth Metals
Carbonates	Stable $Na_2CO_3 \xrightarrow{\Delta} \text{No Reaction}$	Unstable $CaCO_3 \xrightarrow{\Delta} CaO + CO_2$
Bicarbonates	Unstable $2NaHCO_3 \xrightarrow{\Delta} Na_2CO_3 + CO_2 + H_2O$	Unstable $Ca(HCO_3)_2 \xrightarrow{\Delta} CaO + H_2O + 2CO_2$
Sulphates	Stable $Na_2SO_4 \xrightarrow{\Delta} \text{No Reaction}$	Stable

3. Some Basic Chemical Equations :



PROBLEM SOLVING TECHNIQUE (Using Mole Concept)

Follow the given sequence :

1. First write a balanced chemical equation.
2. Analyse the reactants and products according to their respective stoichiometric coefficients i.e.
i.e. m mole of A $\equiv$ n moles of B $\equiv$ p moles of C $\equiv$ q moles of D
3. According to data given, proceed as explained in the above illustration
4. In stoichiometric problems involving gases, we will assume all the gases to be ideal and apply
Gas Equation : $PV = nRT$.

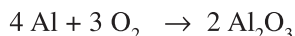
(P : Pressure of gas in atm units, V : Volume of gas in L and T : Temperature in Kelvin and R : Universal gas constants = $0.0821 \text{ atm L mol}^{-1} \text{ K}^{-1}$)

- (a) At S.T.P., the volume occupied by 1 mole of a gaseous compound is equal to 22.4 L (or 22400 mL). This is also called as **Molar volume**.
- (b) At room temperature, $T = 298 \text{ K}$, $P = 1.0 \text{ atm}$., volume of 1 mole of gas is 24.48 L.
- (c) N.T.P. (Normal temperature and pressure) condition is same as S.T.P. condition.

Illustration - 7 A flash bulb used for taking photograph in poor light contains 30 mL of O_2 at 780 mm pressure at 27°C . Suppose that metal wire flashed in the bulb is pure Aluminium (Al) and it is oxidised to Al_2O_3 in the process of flashing, calculate the minimum weight of Al-wire that is to be used for maximum efficiency.

Solution :

Al is oxidised to Al_2O_3 as follows.



First, calculate the moles (n) of O_2 .

Use $PV = nRT$

$$\Rightarrow n = \frac{PV}{RT} = \frac{(780/760) (30/1000)}{0.081 \times 300} \approx 1.25 \times 10^{-3}$$

From stoichiometry of the reaction :



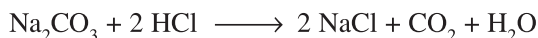
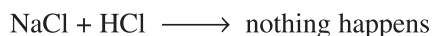
$$1.25 \times 10^{-3} \text{ mole of } O_2 \equiv \frac{4}{3} (1.25 \times 10^{-3}) \text{ mole of Al}$$

$$\text{gram of Al} = \frac{4}{3} (1.25 \times 10^{-3}) \times 27 = 0.045 \text{ gm}$$

Illustration - 8 A mixture of $NaCl$ and Na_2CO_3 is given. On heating 12 gm of the mixture with dilute HCl , 2.24 gm of CO_2 is evolved at normal temperature. Calculate the amounts of two components in the mixture.

Solution :

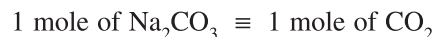
Consider the effect of heat on the mixture.



Let x grams of Na_2CO_3 are there in the mixture.

$$\Rightarrow \text{moles of } Na_2CO_3 = \frac{g}{M_0} = \frac{x}{106}$$

From stoichiometry, we have :



$$\frac{x}{106} \text{ moles of } Na_2CO_3 = \frac{x}{106} \text{ mol of } CO_2$$

$$\Rightarrow \frac{x}{106} = \frac{2.24}{44} \quad \text{or} \quad x = 5.4 \text{ gm.}$$

$$\begin{aligned} \text{Hence grams of NaCl in the mixture} \\ = 12 - x = 6.60 \text{ gm} \end{aligned}$$

Illustration - 9 A mixture of FeO and Fe_3O_4 when heated in air to a constant weight, gains 5% of its weight. Find the composition of the initial mixture.

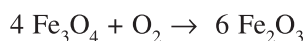
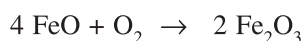
Solution :

In such type of problems, in order to simplify the calculations, let us assume that the initial weight of the mixture is 100 gm.

Then the final weight of the mixture after heating in air will be 105 gm.

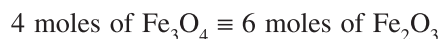
Let x be the weight of FeO in the initial mixture, then the weight of $\text{Fe}_3\text{O}_4 = 100 - x$

When the mixture is heated in air (O_2):



$$\Rightarrow 4 \text{ moles FeO} \equiv 2 \text{ moles of Fe}_2\text{O}_3$$

$$\Rightarrow \frac{x}{72} \text{ moles} \equiv \frac{x}{144} \text{ moles of Fe}_2\text{O}_3$$



$$\Rightarrow \frac{100-x}{232} \text{ moles} \equiv \frac{6}{4} \left(\frac{100-x}{232} \right) \text{ moles of Fe}_2\text{O}_3$$

$$\text{Total moles of Fe}_2\text{O}_3 = \frac{x}{144} + \frac{6}{4} \left(\frac{100-x}{232} \right)$$

$$\text{Weight of Fe}_2\text{O}_3 = \left[\frac{x}{144} + \frac{6}{4} \left(\frac{100-x}{232} \right) \right] 160 = 105$$

Solving for x , we get ;

$$x = 20.25 \text{ gm} = \text{weight of FeO}$$

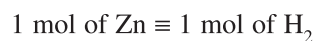
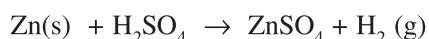
$$\Rightarrow \text{weight of Fe}_3\text{O}_4 = 100 - x = 79.75 \text{ gm.}$$

$$\% \text{FeO} = 20.25 \quad \text{and} \quad \% \text{Fe}_3\text{O}_4 = 79.75$$

Illustration - 10 Brass is an alloy of Cu-Zn. A sample of brass weighing 6.0 g, when treated with excess of dil. H_2SO_4 gives 328 mL of dry H_2 at 27°C and 760 mm pressure. What is the percentage of Cu by weight in the alloy? (Atomic mass of Zn = 65.4 gm)

Solution :

Only Zn reacts with dil. H_2SO_4 and produces H_2 , whereas Cu does not.



$$\Rightarrow \text{moles of H}_2 \text{ evolved} = n = \frac{PV}{RT}$$

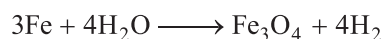
$$n = \frac{760/760 \times 0.328}{0.082 \times 300} = 0.0133$$

$$\text{The amount of Zn in the alloy} = 0.0133 \times 65.4 = 0.87 \text{ g}$$

$$\text{or } \% \text{Cu} = \frac{5.13}{6.0} \times 100 = 85.5\%$$

Illustration - 11 Calculate the weight of iron which will be converted into its oxide by the action of 18g of steam.

Solution : Remember that iron reacts with steam, it forms Fe_3O_4



From stoichiometry of the reaction : 3 moles of Fe $\equiv$ 4 moles H_2O

$$\text{Moles H}_2\text{O} = \frac{18}{18} = 1$$

$$\text{Moles Fe} = \frac{3}{4} \times 1 = \frac{3}{4}$$

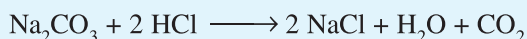
$$\text{Weight of Fe} = \frac{3}{4} \times 56 = 42\text{g}$$

Important Concepts in Stoichiometric Calculations :

1. (a) Finding the Equivalent Weight of Basic Compounds :

Oxides, Carbonates and Bicarbonates of alkali metals and alkaline earth metal are basic in nature e.g. MgO , Na_2CO_3 and NaHCO_3 are basic.

The n-factor (acidity of carbonates, bicarbonates & oxides) is equal to the magnitude of total charge on cations or anions. It can also be confirmed by visualizing the neutralisation reaction as follows :



The above reaction shows that 1 mole of Na_2CO_3 requires two moles of H^+ ions. Thus, its equivalent weight is $\frac{106}{2}$ i.e. 53 gm/mol. [**Note:** Acidity also refers to the number of H^+ ions required to react with the base.]

(b) Finding the Equivalent Weight of Acidic Compounds :

The oxides of non-metals are acidic in nature, such as SO_2 & SO_3 are popular acidic oxides used in neutralisation.

The n-factor (basicity) can be determined as follows :



The above reaction shows that 1 mole of SO_3 requires two moles of OH^- ions. Thus, its equivalent weight is $80/2 = 40$ gm/mol. **Note :** Basicity also refers to the number of OH^- ions required to react with the acid.

2. Concept of Limiting Reagent :

Whenever, the amount of two reacting species (reagents) is given, very rarely they react completely (unless calculated beforehand). In such cases, one of reagent reacts completely (as per Stoichiometry of the reaction) leaving behind the other in excess. The reagent which reacts completely is known as **Limiting Reagent**.

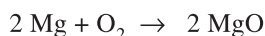
Determine the limiting reagent is rather easy and works well with this short formula :
$$\frac{\text{Moles of reagent taken}}{\text{Stoichiometric coefficient}}$$
 Whichever reactant has the lowest value of this ratio is the limiting reagent.

Illustrating the Concept :

A closed vessel is found to contain 192 gm of Mg and 96 gm of O_2 . This mixture is burnt.

(a) Which is the limiting reagent?

(b) Find the weight of reagent in excess (the other one)?



2 moles of Mg $\equiv$ 1 mole of $\text{O}_2 \equiv$ 2 moles of MgO

$$\text{Initial moles of Mg} = \frac{192}{24} = 8$$

$$\text{Initial moles of O}_2 = \frac{96}{32} = 3$$

1 mole of $\text{O}_2 \equiv$ 2 moles of Mg

$$\Rightarrow 3 \text{ moles of O}_2 \equiv \frac{2}{1} \times 3 = 6 \text{ moles of Mg}$$

$\Rightarrow$ Mg is in excess.

Hence O_2 is the limiting reagent as it is consumed fully.

Excess of Mg = 8 – 6 = 2 moles

$$\Rightarrow \text{Grams of excess Mg} = 2 \times 24 = 48 \text{ gm}$$

moles of MgO formed = moles of Mg consumed = 6

$$\Rightarrow \text{Grams of MgO formed} = 6 \times 40 = 240 \text{ gm}$$

Read the following Illustrations carefully to understand the concept of limiting reagent.

IN-CHAPTER EXERCISE-C

1. Fill in the blanks :

- (a) The residue obtained on strongly heating 2.76 g Ag_2CO_3 is _____
 $[\text{Ag}_2\text{CO}_3 \xrightarrow{\Delta} \text{Ag} + \text{CO}_2 + \text{O}_2]$ [Atomic mass of Ag = 108]
- (b) 5 gm of K_2SO_4 were dissolved in 250 ml of solution. The volume of this solution that should be used so that 1.2 gm of BaSO_4 may be precipitated from BaCl_2 is _____ (Mol. Mass of $\text{K}_2\text{SO}_4 = 174$ and $\text{BaSO}_4 = 233$)
- (c) 2 moles of $\text{Ca}(\text{HCO}_3)_2$ on heating forms 1 mole of CO_2 . The % yield of CO_2 is _____
- (d) The equivalent weight of NaHCO_3 is _____ and of SO_2 is _____

2. Choose the correct option for each of the following question. Only One choice is Correct.

- (i) A reaction occurs between 3 moles of H_2 and 1.5 moles of O_2 to give some amount of H_2O . The limiting reagent in this reaction is :
 (A) H_2 (B) O_2 (C) H_2 and O_2 both (D) Neither of them
- (ii) $4\text{I}^- + \text{Hg}^{2+} \longrightarrow \text{HgI}_4^{2-}$; 1 mole each of Hg^{2+} and I^- will form :
 (A) 1 mole of HgI_4^{2-} (B) 0.5 mole of HgI_4^{2-} (C) 0.25 mole of HgI_4^{2-} (D) 2 mole of HgI_4^{2-}
- (iii) Hydrogen peroxide in aqueous solution decomposes on warming to give oxygen according to the equation,

$$2\text{H}_2\text{O}_2(\text{aq}) \longrightarrow 2\text{H}_2\text{O}(\ell) + \text{O}_2(\text{g})$$

 Under conditions where 1 mole of gas occupies 24 dm^3 , 100 cm^3 of X M solution of H_2O_2 produces 3 dm^3 of O_2 . Thus X is :
 (A) 2.5 (B) 1 (C) 0.5 (D) 0.25
- (iv) A certain compound has the molecular formula X_4O_6 . If 10 g of X_4O_6 has 5.72 g X, atomic mass of X is :
 (A) 32 amu (B) 37 amu (C) 42 amu (D) 98 amu
- (v) How many moles of magnesium phosphate, $\text{Mg}_3(\text{PO}_4)_2$ will contain 0.25 moles of oxygen atoms ?
 (A) 0.02 (B) 3.125×10^{-2} (C) 1.25×10^{-2} (D) 2.5×10^{-2}
- (vi) On heating 1.763 g of hydrated BaCl_2 gave 1.505 g of anhydrous salt remained. What is the formula of hydrate?
 (A) $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ (B) $\text{BaCl}_2 \cdot \text{H}_2\text{O}$ (C) $\text{BaCl}_2 \cdot 3\text{H}_2\text{O}$ (D) $\text{BaCl}_2 \cdot 4\text{H}_2\text{O}$
- (vii) Equal weights of Zn metal and iodine are mixed together and I_2 is completely converted to ZnI_2 . What fraction by weight of original Zn remains unreacted ? (Zn = 65, I = 127)
 (A) 0.34 (B) 0.74 (C) 0.84 (D) Unable to predict
- (viii) How many moles of P_4 can be produced by reaction of 0.10 moles $\text{Ca}_5(\text{PO}_4)_3\text{F}$, 0.36 moles SiO_2 and 0.90 moles C according to the following reaction ?

$$4\text{Ca}_5(\text{PO}_4)_3\text{F} + 18\text{SiO}_2 + 30\text{C} \longrightarrow 3\text{P}_4 + 2\text{CaF}_2 + 18\text{CaSiO}_3 + 30\text{CO}$$

 (A) 0.060 (B) 0.030 (C) 0.045 (D) 0.075
- (ix) In an experiment, 6.67 g of AlCl_3 was produced and 0.54g Al remained unreacted. How many moles of Al were taken originally ?
 (A) 0.07 (B) 0.06 (C) 0.05 (D) 0.02
- (x) One mole of potassium chlorate is thermally decomposed and excess of aluminium is burnt in the gaseous product. How many mole(s) of aluminium oxide are formed?
 (A) 1 (B) 1.5 (C) 2 (D) 3