

## Solutions-1

PART-1: Introduction, Methods of expressing concentration

### 1. Solution

Homogeneous mixture of two or more substances whose composition vary within certain limits is known as Solution or a True Solution.

Eg: Salt in water, sugar in water.

In a homogeneous mixture composition is same throughout the mixture.

A solution contains only two components is called a binary solution. The two components are solute and solvent.

The component present in lesser proportion (or) dissolved state is solute and the component present in greater proportion (or) dissolving medium is a solvent.

### 2. Characteristics of a solution

- i. It is a homogeneous mixture.
- ii. Formation of solution is a physical change but not a chemical change.
- iii. Solute cannot be separated from solution by filtration.
- iv. Solute can be separated from solution by distillation, absorption (or) Crystallization.

If the solute is non-volatile and solvent is volatile then they are separated by evaporation

(Or) distillation

- v. The properties of a solution like density, vapour pressure, boiling point depend on relative amount of solute and solvent.

### 3. Solubility

i. Solubility (s) is the number of grams of the solute that dissolves in 100grams of a solvent at a given temperature to make a saturated solution.

$S = \frac{w \times 100}{m}$ , where  $w$  is wt of solute and  $m$  is wt of solvent.

ii if Solubility,  $S > 1\text{g/ml}$  ,  $S < 0.001\text{g/ml}$  ,  $S = 0.001-1\text{g/ml}$

Soluble

Insoluble

sparingly soluble

iii. Solubility depends on the nature of solute, solvent, temperature and pressure. It has no units.

It is related to Molarity as ,  $m = \frac{S \times 10}{GMW}$

4. Solubility of a solid in a liquid depends on Lattice and Hydration energies. The heat liberated or absorbed when one mole of solute is dissolved in excess solvent is known as Heat of solution. It is the algebraic sum of lattice and hydration energies.

i. If lattice energy  $>$  hydration energy, endothermic change takes place. The vessel becomes cool.

eg.  $\text{NH}_4\text{Cl}$ ,  $\text{AgNO}_3$ , Hypo.

The solubility of these substances increases with temperature.

ii. If hydration energy  $>$  lattice energy, exothermic change takes place. The vessel becomes warm.

eg.  $\text{Na}_2\text{CO}_3$ ,  $\text{NaOH}$ ,  $\text{H}_2\text{SO}_4$ ,  $\text{Na}_2\text{SO}_4$ . Etc.,

The solubility of these substances decreases with temperature.

iii. If hydration energy = lattice energy, heat is neither evolved nor absorbed.

eg.  $\text{NaCl}$

The solubility of these substances independent of temperature

5. The solubility of a solid or liquid in a liquid follows the principle 'Like dissolves

like', the. Solubility of a gas in water generally decreases with increase in temperature and increases with increase in pressure.

6. Solubility of a gas in a liquid is expressed in terms of absorption coefficient.

The volume of the gas at NTP dissolved in a unit volume of solvent at a temperature and

1 atm pressure is called absorption coefficient.

Factors influencing the solubility of a gas in a liquid are:

I) Nature of gas and liquid

ii) Temperature

iii) Pressure of the gas

With an increase in the pressure, the number of gaseous molecules per unit volume over the solution increases. Thus solubility of gas increases.

Conditions for high solubility of gas in a liquid are

i) High pressure

ii) Low temperature

(For the dissolution of gases in liquids, Heat of solution is always negative, because lattice energy is zero)

7. **Henry's law:** At a given temperature, the mass of a gas (m) dissolved per unit volume of a solvent is proportional to the pressure of the gas (p)."

At constant temperature,

$$m \propto p \quad \text{or} \quad m = kp \quad (\text{k is constant})$$

The partial pressure of the gas in vapour phase (p) is directly proportional to the mole fraction

Of gas (X) in the solution  $p = K_H X$ , where  $K_H$  is Henry's law constant.

It is to be noted that the higher the value of Henry's law constant, the lower is the solubility of the gas in the liquid.

Henry's law is not applicable to the gases which react with solvent.

Eg.  $\text{NH}_3$  &  $\text{HCl}$  react with water.

### 8. Applications of Henry's Law

- i) Increase in the solubility of  $\text{CO}_2$  in soda water is due to high pressure of the gas
- ii) At higher altitudes the partial pressure of oxygen is less. This leads to lower concentration of oxygen in blood and tissues of mountain climbers and people living at higher altitudes. Due to lower pressure of oxygen Persons become weak and unable to think properly. These symptoms are called 'anoxia'.

### 9. Types of Solution: (Based on Nature of Solvent)

1. Aqueous Solutions (Solvent is water)
2. Non-Aqueous Solutions (Solvent is other than  $\text{H}_2\text{O}$ )
  - i Solutions with alcohol as solvent are called alcoholic solutions.
  - ii. Solutions with Ether as solvent are called ethereal solutions.
  - iii. Solutions with liq. Ammonia as solvent are called Ammoniacal solutions.
  - iv. In Amalgams - mercury is one of the components.

The commonly used Solvents in non-aqueous Solutions are

liq. $\text{NH}_3$ , liq. $\text{SO}_2$ ,  $\text{CHCl}_3$ ,  $\text{C}_6\text{H}_6$ ,  $\text{CS}_2$  , acetic acid etc.

### 10. Types of solutions and common examples

Type of solution	Solute	Solvent	Common example
Solid solutions	Solid	Solid	Copper dissolved in gold
	Liquid	Solid	Amalgam of mercury with sodium
	Gas	Solid	Solution of hydrogen in palladium
Liquid solutions	Solid	Liquid	Sugar dissolved in water
	Liquid	Liquid	Ethyl alcohol dissolved in water
	Gas	Liquid	Carbondioxide dissolved in water
Gaseous solutions	Solid	Gas	Camphor in air

Liquid	Gas	Moisture in air
Gas	Gas	Mixture of any two gases.[CO+H <sub>2</sub> ]

## 11. Methods of Expressing Concentrations

The quantity of solute present in definite quantity of the solution relative to the solvent is known as Concentration of solution or strength of solution.

- The solution with known concentration is called a **STANDARD SOLUTION**
- The solution containing relatively smaller quantity of solute compared to that of solvent is called a **DILUTE SOLUTION**.
- The solution which contain excess solute, in a definite quantity of the solution is called a **CONCENTRATED SOLUTION**:
- The ratio between density of solution and density of water at the given temperature is known as relative density or specific gravity of solution.

Specific gravity = density of solution / density of water

Specific gravity has no units.

### 1.2: Physical methods

- Weight Fraction:** It is amount of solute in grams present in 100g solution  
Weight Fraction = wt of solute / wt of solution  
Weight % = [wt of solute / wt of solution] X100
- Volume fraction** = Vol. of solute / vol. of solution  
Volume % = [Vol. of solute / vol. of solution] X100
- mass/volume percentage:** It is mass of solute dissolved in 100 ml of solution.  
 $w/v\% = [\text{wt. of solute} / \text{vol. of solution}] \times 100$
- PPM (PARTS PER MILLION):** It is the mass of the solute present in million parts by mass of the solution

\*Molarity, mole fraction and wt. fraction do not change with temperature

### 1.3: Chemical Methods

I. **Molarity: - (M)** It is number of gram moles of solute dissolved per litre of solution.

Unit = Moles/litre

Molarity decreases with increase in temperature.

$$M = \frac{n}{V_{\text{Lit}}}$$

n = number of moles of solute

V = Volume of Solution in litres.

$$M = \frac{w}{\text{GMW}} \times \frac{1000}{V} \quad \therefore n = \frac{w}{\text{GMW}}$$

w = weight of the solute in grams

v = volume of the solution in millilitres

GMW = molecular weight of the solute in grams

- 1) Number of millimoles of the solute present in V ml. of the solution = Volume of solution in ml. X Molarity = VM
- 2) Number of moles of solute present in Vml. of the solution = VXM/1000
- 3) Number of moles of solute present in V litres of solution = M V
- 4) When a solution is diluted its molarity decreases, but number of moles of solute before & after dilution remains constant.

$$V_1M_1 = V_2M_2$$

V<sub>1</sub> = Volume of the solution before dilution.

M<sub>1</sub> = Molarity of the solution before dilution.

V<sub>2</sub> = Volume of the solution after dilution.

M<sub>2</sub> = Molarity of the solution after dilution.

5) Volume of water added to get a solution of known molarity =  $V_2 - V_1$  or  $(M_1 - M_2)V_1/M_2$

6) When weight/volume percentage is given,

$$M = \frac{10 \times (w/v)\%}{GMW}$$

7) When weight percentage of solution and specific gravity or density are given then

$$M = \frac{10 \times d \times (w/w)\%}{GMW}$$

Where  $w/w\%$  = percentage by weight

$d$  = Density in gram/ml

8) For a mixture of two solutions of different molarities, the molarity of the resulting solution is given by

$$M = \left[ \frac{V_1 M_1 + V_2 M_2}{V_1 + V_2} \right]$$

9) When two solutions are titrated against each other as per the following equation

$n_1 A + n_2 B \rightarrow m_1 C + m_2 D$ , The molarities of the two solutions are related as

$$\frac{M_1 V_1}{n_1} = \frac{M_2 V_2}{n_2}$$

**II. Normality:** It is number of gram equivalents of solute dissolved per litre of solution.

Unit = gm. equivalents / litre

Normality decreases as temperature increases.

$$i. N = \frac{\text{number of equivalents of solute}}{\text{volume of solution in litres}} \quad (\text{or}) \quad N = \frac{\text{wt of solute}}{\text{Gram equivalent weight}} \times \frac{1000}{\text{Vol of solution in ml}}$$

a) Equivalent weight of an Acid

$$E_{\text{Acid}} = \frac{\text{Formula weight of acid}}{\text{Basicity of acid}}$$

Number of replaceable hydrogen's present in one molecule of acid is called its basicity.

Equivalent weights of some acids

Acid	Formula	Formula Weight	Basicity	Equivalent weight
Hydrochloric acid	HCl	36.5	1	36.5
Sulphuric acid	H <sub>2</sub> SO <sub>4</sub>	98	2	49
Nitric acid	HNO <sub>3</sub>	63	1	63
Acetic acid	CH <sub>3</sub> COOH	60	1	60
Oxalic acid	H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> .2H <sub>2</sub> O	126	2	63
Phosphoric acid	H <sub>3</sub> PO <sub>4</sub>	98	3	32.67
Phosphorous acid	H <sub>3</sub> PO <sub>3</sub>	82	2	41
Hypophosphorus acid	H <sub>3</sub> PO <sub>2</sub>	66	1	66

b. Equivalent weight of base =  $\frac{\text{Formula weight of base}}{\text{Acidity of base}}$

Equivalent weights of some bases

base	Formula	Formula weight	Acidity	Equivalent weight
Sodium hydroxide	NaOH	40	1	40
Potassium hydroxide	KOH	56	1	56
Calcium hydroxide	Ca (OH) <sub>2</sub>	74	2	37
Aluminium hydroxide	Al (OH) <sub>3</sub>	78	3	26



Ferrous hydroxide	Fe (OH) <sub>2</sub>	90	2	45
Ferric hydroxide	Fe (OH) <sub>3</sub>	107	3	35.67
Ammonium hydroxide	NH <sub>4</sub> OH	35	1	35
Chromic hydroxide	Cr (OH) <sub>3</sub>	103	3	

34.33

c. Equivalent weight of salt

$$E_{\text{salt}} = \frac{\text{Formula weight of the salt}}{\text{Total charge of the cation or anion of the salt}}$$

$$E_{\text{Al}_2(\text{SO}_4)_3} = \frac{F}{6} = \frac{342}{6} = 57$$

d. Equivalent weight of Ion =  $\frac{\text{Formula weight}}{\text{Charge / Valency}}$ ,  $E_{\text{Fe}^{2+}} = \frac{56}{2} = 28$

e. Equivalent weight of oxidising agent =  $\frac{\text{Formula weight of oxidant}}{\text{Electrons gained by one molecule of oxidant}}$

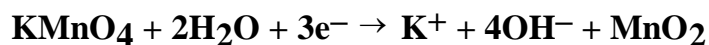
eg: **KMnO<sub>4</sub>** acts as oxidant in acidic, basic and also in neutral medium.



One molecule of **KMnO<sub>4</sub>** gains five electrons. Hence, the equivalent weight of **KMnO<sub>4</sub>**

$$= \frac{\text{Mol. wt. of KMnO}_4}{5} = \frac{158.04}{5} = 31.608$$

2. In neutral as well as weakly basic medium



One molecule of **KMnO<sub>4</sub>** gains three electrons.

Hence The equivalent weight of

$$\text{KMnO}_4 = \frac{\text{Mol.wt.of KMnO}_4}{3} = \frac{158.04}{3} = 52.68$$

**3. In strongly alkaline medium:**  $\text{MnO}_4^- + e^- \rightarrow \text{MnO}_4^{2-}$

$$\text{Then the equivalent weight of KMnO}_4 = \left\{ \frac{\text{Mol.wt.of KMnO}_4}{1} \right\} = 158.04$$

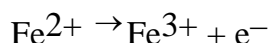
f. Equivalent weight of reducing agent

$$E_{\text{reductant}} = \frac{\text{Formula weight of reductant}}{\text{Electrons lost by one molecule of reductant}}$$

Mohr's salt is ferrous ammonium sulphate

Formula =  $\text{FeSO}_4 (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$

Formula weight = 392



**The equivalent weight of Mohr's salt is  $392/1 = 392$**

Some useful relations

- i) Number of equivalents of solute =  $V \times N$ , volume V is in litres.
- ii) Number of mill equivalents of solute =  $V \times N$ , volume V is in millilitres.
- iii) The mass of a solute (w) in grams, present in V litres of a solution, can be calculated from normality of the solution (N) as,

$$w = N \times V \times \text{GEW}$$

Here GEW is the gram equivalent weight of solute.

- iv) Normality of the mixture when two solutions of same solute are mixed

$$N = \frac{N_1 V_1 + N_2 V_2}{V_1 + V_2}$$

- v) When  $V_a$  ml of a strong acid of normality  $N_a$  is mixed with  $V_b$  ml of a strong base of normality  $N_b$ ,

- i) If  $N_a V_a = N_b V_b$  the solution is neutral

ii) If  $N_a V_a > N_b V_b$ , the solution is acidic. Normality w.r.t  $H^+$

$$= \frac{N_a V_a - N_b V_b}{V_a + V_b}$$

iii) If  $N_a V_a < N_b V_b$ , the solution is basic

$$\text{Normality w.r.t } OH^- = \frac{N_b V_b - N_a V_a}{V_a + V_b}$$

vi) **Normality, Molarity interrelation:**

i) **For acids: Normality = Molarity X Basicity of acid**

ii) **For bases: Normality = Molarity X Acidity of base**

iii) **For salts: Normality = Molarity X total +ve or -ve charge of the salt**

iv) **For oxidising (or) reducing agents :**

Normality = Molarity X total change in oxidation state per mole of oxidant or reductant

vii) **For exact neutralisation of acid with base**

$$\frac{\text{wt of base}}{\text{GEW of base}} = \frac{N_a V_a (\text{ml})}{1000} ; \frac{\text{wt of acid}}{\text{GEW of acid}} = \frac{N_b V_b (\text{ml})}{1000}$$

viii) In case of dilution:  $V_1 N_1 = V_2 N_2$ , The volume of the solution before and after dilution are  $V_1$  and  $V_2$  and normalities are  $N_1$  and  $N_2$  respectively.

### III. Molality

**It is defined as the number of gram moles of the solute present in one kilogram of solvent. It is denoted by 'm'. Units of molality are mol kg<sup>-1</sup>.** It is independent of temperature. Molality is the most accurate and theoretically the best method of expressing concentration.

Molality (m) is given as

$$m = \frac{\text{number of moles of solute (n)}}{\text{number of kg of solvent (W)}} \quad (\text{Or}) \quad m = \frac{w}{\text{GMW}} \times \frac{1000}{W}$$

Here  $w$  and  $W$  are masses of solute and solvent respectively in grams.  $GMW$  is the gram molecular mass of solute.

Some useful relations

i. 
$$m = \frac{10 \times \text{Solubility}}{\text{Gram molecular weight}}$$

ii. 
$$m = \frac{\text{Molarity} \times \text{Vol in lit}}{\text{weight of solvent in kg}}$$

iii. 
$$m = \frac{1000 \times \text{Molarity}}{(1000 \times \text{specific gravity}) - M \times GMW}$$

iv. Mole fraction of solute =

$$\frac{m}{m + \left( \frac{1000}{MW \text{ of solvent}} \right)}$$

#### IV: Mole fraction

It is the ratio of number of moles of a component to the total number of moles of the solution. It is denoted by the symbol 'X'. If number of moles of component substances A and B in a solution are respectively  $n_A$  and  $n_B$ ,

$$\text{Mole fraction of component A} = n_A = \frac{n_A}{n_A + n_B}$$

$$\text{Mole fraction of component B} = n_B = \frac{n_B}{n_A + n_B}$$

The sum of the mole-fractions of all components in a solution is unity. Mole fraction is very useful in calculations involving gas mixtures and also in relating some physical properties like vapour pressure.

**One hundred times mole fraction is called mole percentage. Mole fraction and mole percentage have no units. They do not vary with a change in temperature of solution.**