Solutions, Dilute Solutions and Colligative Properties

A solution is a homogeneous mixture of two or more substances whose composition can be varied within certain limits. The components of a binary solution are generally refered as solute and solvent. The component present in excess is called solvent and the component present in ~~excess~~ lesser is called ~~solvent~~ solute. A solute is a substance that dissolve and solvent is a substance in which dissolution takes place.

Liquid solution: All liquids donot form homogeneous solutions. depending upon their solubility and mobility they are classified into three types:

1) The two components are completely miscible: The two liquids are of some nature both polar or both non-polar (benzene and hexane) ethyl alcohol and water.

ii) The two components are almost immiscible: One liquid is polar while the other is nonpolar in nature eg benzene and water.

iii) The two components are partially miscible: when they are partially immiscible eg ether and water.

Expressing Concentration of a solution: The conc^n^ of a sol^n^ is defined as the amount of solute present in the given quantities of the sol^n^.

1) **Mass percentage or volume percentage**: The mass percentage of a component in a given solution is the mass of the component per 100 gm of the sol^n^. If W_A is the mass of component A and W_B is the mass of component B in a sol^n^

$$\text{Mass percentage of A} = \frac{W_A}{W_A + W_B} \times 100$$

Eg. 10% sol^n^ of NaCl means 10gm of NaCl is present in 90gm of water so that total mass of the sol^n^ is 100gm or 10gm of sod chloride is present in 100gm of sol^n^.

ii) Volume percentage : When liquid dissolved in another liquid the conc^n is expressed in vol. %. The vol % is defined as the vol. of the component per 100 parts by vol. of the sol^n. Eg if V_A and V_B are vol of two component A and B in a sol^n.

$$\text{Vol \% of A} = \frac{\text{Vol A}}{\text{Vol A} + \text{Vol B}} \times 100 \quad V/V$$

Sometimes expressed as W/V eg 10 % Sol^n of NaCl that 10gm of NaCl are dissolved in 100ml of sol^n.

iii) Parts per Million : When solute is present in very minute amount the conc^n is expressed in parts per million ab as ppm. It is the parts of a component per million parts of the sol^n.

$$\text{ppm A} = \frac{\text{Mass of Component A}}{\text{Total mass of sol}^n} \times 10^6$$

Eg A litre of public supply water contains about 3×10^{-3}gm of Chlorine. The mass % of Chlorine is

$$\text{Mass \% of Chlorine} = \frac{3.0 \times 10^{-3}}{1000} \times 100 = 3 \times 10^{-4} \text{ total vol in 100ml}$$

The parts per million parts of Chlorine is

$$\text{ppm of Chlorine} = \frac{3 \times 10^{-3} \times 10^6}{1000} = 3 \text{ ppm}$$

Ex : If 11gm of oxalic acid are dissolved in 500ml of sol^n (density 1.1gm/ml) what is mass % of oxalic acid in solution?

11gm of oxalic acid are present in 500ml of sol^n.

Density of sol^n = 1.1 gm/ml

Mass of sol^n = 500 × 1.1 = 550 gm.

Mass of oxalic acid = 11gm

$$\text{Mass \% of oxalic acid} = \frac{11}{550} \times 100 = 2\%$$

Molarity of a solution: The no. of moles of the solute dissolved per litre of the soln.

Eg 1M Na_2CO_3 (molar mass = 106) soln has 106 gm of the solute present per litre of soln

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{vol. of soln in litres}}$$

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Vol. of soln in ml or cm}^3} \times 1000$$

The unit of molarity are moles per litre (mol/L) or moles per cubic decimetres (mol/dm^3)

$$\text{Molarity} = \frac{n_B}{V} \times 1000$$

$$\text{moles of solute} = \frac{\text{mass of solute}}{\text{molar mass of solute}}$$

Molality of a solution: It is the no of moles of the solute dissolved per 1000 gm (1Kg) of the solvent. (m)

$$\text{Molality (m)} = \frac{\text{moles of solute}}{\text{weight of solvent in Kg}}$$

$$= \frac{\text{Moles of solute}}{\text{mass of solvent in gm}} \times 1000$$

The unit of molality per moles per kilogram mole/Kg

$$\text{Molality} = \frac{n_B}{W} \times 100.$$

Molarity changes with temp because of expansion or conc^n of the liquid while molality does not change with temp. because mass of solvent does not change with temp.

Ex. Calculate the molality of a sol^n containing 20.7 gm of K_2CO_3 dissolved in 500 mL of sol^n. density of sol^n = 1 gm/ml

mass of K_2CO_3 = 20.7 gm, molar mass of K_2CO_3 = 138

Moles of $K_2CO_3 = \frac{20.7}{138} = 0.15$

Mass of sol^n = 500 gm × 1 gm/ml = 500 gm

Amt of water = 500 − 20.7 = 479.3 gm

$$\text{Molality} = \frac{\text{moles of solutes}}{\text{mass of solvent in gm}} \times 1000$$

$$= \frac{0.15}{479.3} \times 1000 = 0.313\,m.$$

4) <u>Moles of fraction</u>: The ratio of number of moles of one component to the total no. of moles (solute and solvent) present in the sol^n. It is denoted by x. Let the sol^n contain n_A moles of solute and n_B moles of solvent.

$$\text{mole fraction of solute } (x_A) = \frac{n_A}{n_A+n_B}$$

$$\text{mole fraction of solvent } (x_B) = \frac{n_B}{n_A+n_B}$$

The sum of mole fractions of all the component in sol^n is always equal to one as

$$x_A + x_B = \frac{n_A}{n_A+n_B} + \frac{n_B}{n_A+n_B} = 1$$

$x_A = 1 - x_B$ or $x_B = 1 - x_A$ — mole fraction is independent of temp.

Ex A sol^n is prepared by adding 60 gm of methyl alcohol to 120 gm of water. Calculate the mole fraction of methanol and water

mass of methanol = 60 gm, moles of methanol $= \frac{60}{32} = 1.875$

mass of water = 120 gm, moles of water $= \frac{120}{18} = 6.667$

Total mass of moles = 1.875 + 6.667 = 8.542

mole fraction of methanol = $\frac{1.875}{8.542}$ = 0.220

mole fraction of water = $\frac{6.667}{8.542}$ = 0.780

Normality: It is the no. of gram equivalents of the solute dissolved per litre of the solⁿ. It is denoted by N

$$\text{Normality (N)} = \frac{\text{No. of gram equivalent of solute}}{\text{Vol. of sol}^n \text{ in litres}}$$

$$\text{Normality} = \frac{\text{no of gram equivalents of solute}}{\text{Vol of solution in ml}} \times 1000$$

The units of normality are gm equivalent per litre

$$\text{gram equivalent} = \frac{\text{mass of solute}}{\text{Equivalent mass}}$$

Normality also changes with temp.

$$\text{Normality} = \text{molarity} \times \frac{\text{molar mass}}{\text{Equivalent mass}}$$

for acids Normality = molarity x Basicity

for bases Normality = Molarity x Acidity

Basicity = no of H^+ Acidity = no of OH^-

Ex The normality of solⁿ containing 31.5 gm of hydrated oxalic acid ($H_2C_2O_4 \cdot 2H_2O$) in 1250 ml of solⁿ.

mass of oxalic acid = 31.5 gm

Equivalent of oxalic acid = $\frac{31.5}{63}$ = 0.5 (Eq wt 126/2 = 63

Vol of solution = 1250 ml

Normality = $\frac{0.5}{1250} \times 1000$ = 0.4N.

Numerical

Q1. 2.82 gm of glucose (molar mass = 180) are dissolved in 30 gm of water. Calculate a) molality b) mole fraction of glucose and water

mass of glucose = 2.82 gm moles of glucose = $\frac{2.82}{180}$

mass of water = 30 gm

Molality = $\frac{\text{moles of solute}}{\text{mass of mass}} \times 1000$ $\frac{2.82 \times 1000}{180 \times 30 \times 100}$ = 0.522 m

mole fraction moles of glucose = $\frac{2.82}{180}$ = 0.0157

moles of water = $\frac{30}{18}$ = 1.67

mole fraction = $\frac{0.0157}{0.0157+1.67}$ = 0.009 $\frac{1.67}{0.0157+1.67}$ = 0.991

2. Calculate molarity, normality and molality of H_2SO_4 which is commercially available as 15% H_2SO_4 by weight (density = 1.10 gm/ml)

15% H_2SO_4 means 15 gm of H_2SO_4 present in 100 gm solⁿ

gram moles of H_2SO_4 = $\frac{15}{98}$ Vol of solⁿ = $\frac{\text{Mass}}{\text{density}}$ = $\frac{100}{1.10}$ = 90.9 ml

Molarity of H_2SO_4 = $\frac{\text{moles of } H_2SO_4}{\text{vol of sol}^n} \times 1000$ = $\frac{15 \times 1000}{98 \times 90.9}$ = 1.68 M

Normality Equivalent mass of H_2SO_4 = $\frac{\text{Molar mass}}{2}$ = $\frac{98}{2}$ = 49

gram equivalent of H_2SO_4 = $\frac{\text{Mass of } H_2SO_4}{\text{Equivalent mass}}$ = $\frac{15}{49}$

Normality = $\frac{\text{gram equivalent of } H_2SO_4}{\text{vol}} \times 1000$ $\frac{15 \times 1000}{49 \times 90.9}$ = 3.36 N

Molality: weight of water in soln = 100 - 15 = 85 gm

moles of H_2SO_4 = $\frac{15}{98}$ Molality = $\frac{\text{Moles of } H_2SO_4}{\text{wt of Solvent in gm}} \times 1000$

$= \frac{15 \times 1000}{98 \times 85} = 1.8m.$

Q. calculate volume of 80% H_2SO_4 by weight (density 1.80 gm/ml) required to prepare 1L of 0.2 M H_2SO_4.

80% H_2SO_4 mean 80 gm of H_2SO_4 in 100 gm of soln in water

Moles of H_2SO_4 = $\frac{80}{98}$

Vol of soln = $\frac{\text{Mass}}{\text{density}} = \frac{100\text{gm}}{1.80} = 55.5\text{ml}.$

Molarity = $\frac{80 \times 1000}{98 \times 55.5} = 14.7\text{ M}.$

To calculate the vol of 14.7 M H_2SO_4 required to prepare 1L of 0.2 M H_2SO_4 $M_1V_1 = M_2V_2$

$14.7 \times V_1 = 0.2 \times 1000$

$V_1 = \frac{0.2 \times 1000}{14.7} = 13.60\text{ml}.$

74.5
35.5
39.0

Q Conc H_2SO_4 has density 1.9 gm/ml and is 99% H_2SO_4 by weight calculate molarity of H_2SO_4 in this acid.

moles of H_2SO_4 = ~~$\frac{20}{49}$~~ $\frac{99}{98}$ mass of water = 100 - 99 = 1

~~mass = D × V = 1.9 × 99 = 188.1~~ $V = \frac{M}{8}$

Vol of sol = $\frac{\text{Mass}}{D} = \frac{99}{1.9}$

$\frac{99 \times 1.9 \times 1000}{98 \times 99 \times 10} = 19.38\text{M}.$

99 8
19
1891
99×
1891
10
19

NaOH = 5gm 100 ml   200 ml of $\frac{M}{5}$

23
16
1
40

$M = \frac{\frac{5}{40}}{100} \times 1000$ $\frac{5 \times 1000}{40 \times 100}$

$= \frac{5}{4} M$ $\frac{5}{4} + \frac{1}{5}$

$\frac{25+4}{20} = \frac{29}{20}$

$\frac{29}{300 \times 20} \times 1000$

$= \frac{29}{6}$

$= 4$

$M_1 V_1 = M_2 V_2 + M_3 V_3$

$M_1 (300) = \frac{5}{4} \times 100 + \frac{1}{5} \times 200$

$M_1 = \frac{125 + 40}{300}$

$= \frac{165}{300} = 0.55\ M.$