

Flow Chart Of Complete chapter: NCERT

SOLUTION

Formation of solution
and its type

Solubility of gas in liquid

Henry Law

Vapour Pressure

Raoult's Law

Colligative Properties

Relative lowering of v.p.

Elevation of B.P.

Depression of freezing point

Osmosis and osmotic pressure

Reverse Osmosis

Concentration Terms

Mass Percentage

Volume Percentage

Mole fraction

Parts per million

Molarity

Molality

Types of solution

Ideal
Solution

Non - ideal
Solution

⊕ve Deviation

Azeotrope

⊖ve Deviation

Azeotrope

ABNORMAL MOLECULAR MASS

Solutions

- Solutions are homogeneous mixtures of two or more than two components.
- Homogeneous mixture means composition and properties are uniform throughout the mixture.
- Generally, the components that is present in the largest quantity is known as Solvent.
- Components present in the solution other than solvent, is known as solute.
- Binary Solution = Solvent + Solute

Type of Solution	Solute	Solvent	Common Examples
Gaseous Solutions	Gas	Gas	Mixture of oxygen and nitrogen gases
	Liquid	Gas	Chloroform mixed with nitrogen gas
	Solid	Gas	Camphor in nitrogen gas
Liquid Solutions	Gas	Liquid	Oxygen dissolved in water
	Liquid	Liquid	Ethanol dissolved in water
	Solid	Liquid	Glucose dissolved in water
Solid Solutions	Gas	Solid	Solution of hydrogen in palladium
	Liquid	Solid	Amalgam of mercury with sodium
	Solid	Solid	Copper dissolved in gold

Expressions for concentration of solution

(i) → Mole fraction [x]

[CBSE 2015C, 2012, 2010C]
[Delhi 2012] 1M

mole fraction of a component = $\frac{\text{No. of moles of Component}}{\text{Total no. of moles of all components}}$

→ For a binary mixture (having component A and B), if the no. of moles of A and B are n_A and n_B respectively. Then mole fraction of A will be $x_A = \frac{n_A}{n_A + n_B}$.

$$\text{mole fraction of B} = x_B = \frac{n_B}{n_A + n_B}$$

→ For binary mixture $x_A + x_B = 1$ [Sum of all the mole fractions is unity]

Example → A mixture having two gaseous component $N_2(g)$ and $O_2(g)$ with no. of moles of 10 and 20 respectively. Then what is the mole fraction of both components.

→ Ans: $x_{N_2} = \frac{n_{N_2}}{n_{N_2} + n_{O_2}} = \frac{10}{10 + 20} = \frac{1}{3}$ then $x_{O_2} = 1 - \frac{1}{3} = \frac{2}{3}$.

(ii) → Mass Percentage [W/W] :-

$$\text{Mass \% of a component} = \frac{\text{Mass of the component in solution}}{\text{Total mass of solution}} \times 100$$

→ 10% Glucose in water means 10 g of glucose is dissolved in 90 g of water resulting in 100 g solution.

(iii) → Volume Percentage [V/V] :-

$$\text{Volume \% of a component} = \frac{\text{Volume of the component}}{\text{Total volume of solution}} \times 100$$

→ 10% Ethanol in water means that 10 ml of ethanol is dissolved in water such that total volume of solution is 100 ml.

(iv) → Mass by volume percentage [m/v] :- It is mass of solute dissolved in 100 ml of the solution.

(v) → Parts per million [ppm] :- [It is used when solute quantity is very-very small]

$$\text{Parts per million} = \frac{\text{No. of parts of component}}{\text{Total no. of parts of all components of the solution}} \times 10^6$$

→ Concentration in parts per million can also be expressed as mass to mass (w/w), volume to volume (v/v) and mass to volume (m/v).

$$\text{Percent} \rightarrow \% \frac{W}{V} = \frac{\text{Weight of solute (g)}}{\text{Volume of solution (ml)}} \times 100 \quad \text{similarly; } \text{PPM} \left(\frac{W}{V} \right) = \frac{\text{Weight of solute (g)}}{\text{Volume of soln (ml)}} \times 10^6$$

→ 5.0 PPM O_2 is dissolved in sea - : means 5.0 g of O_2 is dissolved in 10^6 g of sea water.

→ The concentration of pollutants in water and atmosphere is expressed in terms of PPM.

Question :- calculate the mole fraction of ethylene glycol ($C_2H_6O_2$) in a solution containing 20% of $C_2H_6O_2$ by mass?

Answer -: 20% of $C_2H_6O_2$ means, 20 g of $C_2H_6O_2$ is present in 100 g of water.

$$\text{Molar mass of } C_2H_6O_2 = 2 \times 12 + 1 \times 6 + 16 \times 2 = 62 \text{ g/mol.}$$

$$\text{Moles of } C_2H_6O_2 = \frac{20 \text{ g}}{62 \text{ g mol}^{-1}} = 0.322 \text{ mol} = n_{\text{glycol}}$$

$$\text{Moles of water} = \frac{80 \text{ g}}{18 \text{ g mol}^{-1}} = 4.444 \text{ mol} = n_{\text{water}}$$

$$\rightarrow \text{mole fraction of glycol } x_{\text{glycol}} = \frac{n_{\text{glycol}}}{n_{\text{glycol}} + n_{\text{water}}} = \frac{0.322}{0.322 + 4.444} = 0.068$$

$$\rightarrow \text{similarly } x_{\text{water}} = 1 - x_{\text{glycol}} = 1 - 0.068 = 0.932$$

(vi) Molarity [M] :- It is defined as number of moles of solute dissolved in one litre of solution.

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Volume of solution (in litre)}}$$

[CBSE 2015C]
Delhi 2014C
2011
1M

→ Unit -: mol/litre [M]

→ 0.25M solution of NaOH means that 0.25 mol of NaOH has been dissolved in 1 litre.

→ calculate the molarity of a solution containing 5g of NaOH in 450 ml solution?

Answer -: moles of NaOH = $\frac{5 \text{ g}}{40 \text{ g mol}^{-1}} = 0.125 \text{ mol}$, volume of solution in litre = $\frac{450}{1000} = 0.45 \text{ L}$

$$\text{Molarity} = \frac{0.125 \text{ mol}}{0.45 \text{ L}} = 0.278 \text{ mol L}^{-1} = 0.278 \text{ mol dm}^{-3}$$

$$\boxed{1 \text{ Litre} = 1 \text{ dm}^3}$$

Solve this after reading concept of molality

→ A solution of glucose in water is labelled as 10% by weight. What would be the molality of a solution? [Molar Mass of glucose = 180 g mol^{-1}]

[CBSE 2013] **2M**

Answer -: 10% glucose solution by weight means 10 g glucose is present in 100 g solution.
Then weight of water = $100 - 10 = 90 \text{ g}$

$$\text{Molality} = \frac{\text{Moles of solute}}{\text{Mass of solvent (kg)}} = \frac{(10/180) \text{ mol}}{\left(\frac{90}{1000}\right) \text{ kg}} = 0.61 \text{ mol kg}^{-1} = 0.61 \text{ m.}$$

(vii) → Molality [m] :- It is defined as no. of moles of the solute per Kg of solvent.

$$\text{Molality (m)} = \frac{\text{Moles of solute}}{\text{Mass of solvent (kg)}} \quad \text{unit} \rightarrow \frac{\text{mol}}{\text{kg}}$$

→ 1 m solution of KCl means that 1 mol of KCl (74.5 g) is dissolved in 1 kg of water

→ Calculate molality of 2.5 g of ethanoic acid in 75 g of benzene?

Answer :- Molar mass = $\text{CH}_3\text{COOH} = 12 \times 2 + 1 \times 4 + 16 \times 2 = 60 \text{ g mol}^{-1}$

$$\text{Molality of } \text{CH}_3\text{COOH} = \frac{\text{Moles of } \text{CH}_3\text{COOH}}{\text{kg of benzene}} = \frac{(2.5/60)}{(75/1000)} = 0.556 \frac{\text{mol}}{\text{kg}}$$

Main advantage of molality over molarity :- Molality does not change with change in temperature while, molarity decreases with rise in temperature. [Delhi 2014C/2011 2010] 1M

This is because volume depends on temperature ($V \propto T$) but mass does not.

→ Relation between Density, Molarity and Molality :-

If d is density of solution, m is molality and M is molarity, M_2 is molar mass of solute. Then
$$\text{Molality } m = \frac{M \times 1000}{1000 \times d - M \times M_2} \quad (\text{No need to memorise this formula})$$

Question :- Calculate the molarity of 9.8% w/w solution of H_2SO_4 if the density of the solution is 1.02 g ml^{-1} ? Molar mass of $\text{H}_2\text{SO}_4 \rightarrow 98 \text{ g mol}^{-1}$

Answer :- 9.8% solution means 9.8 g of H_2SO_4 is present in 100 g of the solution.

Density of solution = 1.02 g ml^{-1} , Then volume of solution = $\frac{\text{Mass of solution}}{\text{Density of solution}}$

$$\rightarrow \text{Moles of } \text{H}_2\text{SO}_4 = \frac{9.8 \text{ g}}{98 \text{ g mol}^{-1}} = 0.1 \text{ mol}$$

$$= \frac{100}{1.02} = 0.098 \text{ L}$$

$$\rightarrow \text{Molarity} = \frac{0.1 \text{ mol}}{0.098 \text{ L}} = 1.019 = 1.02 \text{ M}$$

Question :- A solution of glucose (Molar mass = 180 g mol^{-1}) in water is labelled as 10% (mass). What would be the molality and molarity of the solution?

Density of solution $\rightarrow 1.2 \text{ g ml}^{-1}$

[Delhi 2014] 3M

Answer - : 10% glucose solution (by mass) means that

mass of glucose = 10g
 mass of solution = 100g
 mass of solvent = 90g

→ Density of solution = 1.2 g ml^{-1}

→ Volume of solution = $\frac{m}{d} = \frac{100 \text{ g}}{1.2 \text{ g ml}^{-1}} = \frac{1000}{12} \text{ ml}$
 $= \frac{1}{12} \text{ Litre}$

Molar mass of glucose
 $\parallel$
 $180 \frac{\text{g}}{\text{mol}}$

Now, Molarity = $\frac{\text{moles of glucose}}{\text{Volume of solution (in L)}} = \frac{(10/180)}{(1/12)} = 0.667 \text{ M}$

Molality = $\frac{\text{moles of glucose}}{\text{mass of solvent (in kg)}} = \frac{(10/180)}{(90/1000)} = 0.617 \text{ m}$

Solubility

- Solubility of a substance is its maximum amount that can be dissolved in a fix amount of solvent.
 - When a solid solute is added to solvent, some solute dissolves and its concentration increases in solution. This process is known as Dissolution.
 - Some solute particles in solution collide with the solid solute particles and get separated out of solution. This process is known as Crystallisation.
 - At point of equilibrium, no. of solute particles going into solution will be equal to solute particles separating out.
 $\text{Solute} + \text{Solvent} \rightleftharpoons \text{Solution}$
 - At this dynamic equilibrium concentration of solute in solution will remain constant at given temperature and pressure.
 - Such a solution in which no more solute can be dissolved at the same temperature and pressure is called a saturated solution.
 - Unsaturated solution : A solution in which more solute can be dissolved.
- Effect of temperature :- If in a nearly saturated solution, the dissolution process is endothermic ($\Delta H > 0$) then on $\uparrow$ of temperature $\Rightarrow$ Solubility $\uparrow$.
- For exothermic ($\Delta H < 0$) then on $\uparrow$ of temperature $\Rightarrow$ Solubility $\downarrow$.
- Pressure does not have any significant effect on solubility of solids in liquids.
 because solid and liquid both are incompressible

Solubility of gas in liquid

→ Factors affecting solubility of gas in liquid : (i) Nature of gas (ii) Temperature
(ii) Nature of liquid (iv) Pressure

Henry Law [Effect of pressure on solubility] :-

"The solubility of a gas in a liquid at a given temperature is directly proportional to the pressure at which it is dissolved."

[CBSE 2011/2012/2010C]
Delhi 2011

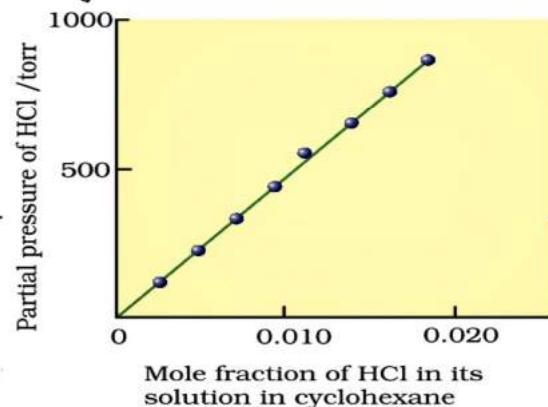
→ If we use mole fraction (x) of a gas in solution as a measure of its solubility, Then →

Partial pressure of a gas (p) = $K_H \cdot x$

1M

Henry Law Constant :-

Henry's Law Constant



(i) K_H is a function of the nature of a gas means that different gases have different K_H value.

(ii) Higher the value of K_H → lower is the solubility because at constant pressure $\Rightarrow K_H \propto \frac{1}{x}$.

(iii) unit of K_H = unit of pressure = atm / torr

→ K_H is proportional to temperature. [$K_H \propto T$ and $K_H \propto \frac{1}{x} \Rightarrow T \propto \frac{1}{x}$]

means that solubility of a gas increases with decrease of temperature.

Due to above reason O_2 is getting more dissolve in cold water than in warm water.

So, aquatic species are more comfortable in cold water than warm water.

1M → [CBSE 2019/2010C]
2M → [Delhi 2012C]

Application of Henry's Law :-

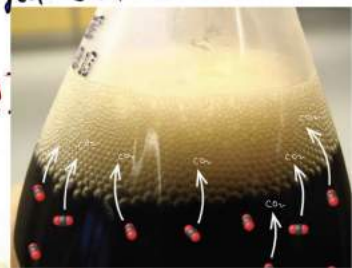
[CBSE 2010] 1M

[i] To increase the solubility of CO_2 in soft drinks and soda water, the bottle is sealed under high pressure.

[ii] At higher altitudes the partial pressure of oxygen is less than that at ground level. This leads to low concentration of oxygen in blood. Low blood oxygen causes climbers to become weak and unable to think clearly, symptoms of a condition known as anoxia.

[CBSE 2019]

1M



Question :- The partial pressure of ethane over a saturated solution containing $6.56 \times 10^{-2} \text{ g}$ of ethane is 1 bar. If solution contains $5.0 \times 10^{-2} \text{ g}$ of ethane, then what will be partial pressure of the gas?

[CBSE 2012C] (3M)
[Delhi 2011C]

Answer :- According to Henry's law -:

(i) mass of ethane $\propto$ partial pressure $[m_1 = K_H \cdot p_1]$

$6.56 \times 10^{-2} \text{ g} = K_H \cdot 1 \text{ bar}$ — (i)

(ii) $m_2 = K_H p_2$

partial pressure of gas (p_2) = $\frac{m_2}{K_H} = \frac{5 \times 10^{-2} \text{ g}}{6.56 \times 10^{-2} \frac{\text{g}}{\text{bar}}} = 0.762 \text{ bar}$. $K_H = 6.56 \times 10^{-2} \frac{\text{g}}{\text{bar}}$

Question :- If N_2 gas is bubbled through water at 293 K, how many millimoles of N_2 gas would dissolve in 1 L of water? Assume that N_2 exerts a partial pressure of 0.987 bar. given $\rightarrow K_H = 76.48 \text{ kbar}$ at 293 K. [CBSE 2012C] (3M)

Answer :- According to Henry's law -: $p_{\text{N}_2} = K_H \cdot x_{\text{N}_2}$

$x_{\text{N}_2} = \frac{p_{\text{N}_2}}{K_H} = \frac{0.987 \text{ bar}}{76.48 \times 10^3 \text{ bar}} = 1.29 \times 10^{-5}$

$\rightarrow$ If n moles of N_2 are present in

1 L or 1000 g of water then moles of

water = $n_{\text{water}} = \frac{1000}{18} = 55.5 \text{ moles}$ [$\text{H}_2\text{O} = 16 + 2 \times 1$]

$\rightarrow$ Mole fraction of $\text{N}_2 = \frac{n}{n + n_{\text{water}}} = \frac{n}{55.5}$ [$n \ll n_{\text{water}}$]

$x_{\text{N}_2} \cdot (55.5) = n \Rightarrow n = 55.5 \times 1.29 \times 10^{-5} = 71.595 \times 10^{-5} \text{ moles}$

$n = 0.716 \times [10^{-3} \text{ moles}] = 0.716 \text{ millimoles}$

Vapour pressure of liquid solutions.

Definition of vapour pressure -: The partial pressure of vapours in equilibrium with pure solid or pure liquid at a given temperature.

At equilibrium: Rate of evaporation = Rate of condensation.

For example -: $\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{O}(\text{g})$ Equilibrium constant (K_p) = $\frac{p_{\text{H}_2\text{O}(\text{g})}}{p_{\text{H}_2\text{O}(\text{l})}}$

For pure $\text{H}_2\text{O}(\text{l})$: $p_{\text{H}_2\text{O}(\text{l})} = 1$ then $K_p = p_{\text{H}_2\text{O}(\text{g})}$

→ For liquid $\rightleftharpoons$ Vapours : Vapour pressure is an equilibrium constant. So it depends only on (a) Nature of liquid (b) Temperature of liquid.

If $\rightarrow$ Magnitude of intermolecular forces in the liquid is smaller then we observe high vapour pressure because loosely held molecules escape more easily into vapour phase.

→ Boiling Point -: The temperature at which vapour pressure of a liquid is equal to external pressure.

→ A liquid having high vapour pressure boils at low temperature. $\left[B.P. \propto \frac{1}{V.P.} \right]$

Vapour pressure of liquid-liquid solutions :-

Raoult's Law :- For a solution of volatile liquids, the partial vapour pressure of each component in the solution is directly proportional to its mole fraction.

→ For a binary liquid-liquid solution

For liquid-1 : $p_1 \propto x_1$

if p_1 and p_2 are partial pressures of liquid-1 and liquid-2 respectively. And x_1 and x_2 are mole fractions of liquid-1 and 2 in solution respectively.

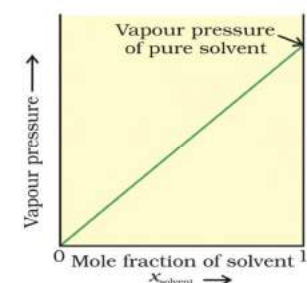
$$p_1 = p_1^0 x_1 \quad \text{--- (i)}$$

$p_1^0 \rightarrow$ Vapour pressure of pure liquid 1

→ For liquid-2 : $p_2 \propto x_2$

$$p_2 = p_2^0 x_2 \quad \text{--- (ii)}$$

$p_2^0 \rightarrow$ Vapour pressure of pure liquid 2.



(1M) [CBSE 2011/2013
Delhi 2011/2010C/2019/2017]

→ According to Dalton's law of partial pressures -: Total pressure over solution phase in the container will be the sum of the partial pressures of components of the solution.

$$p_{\text{total}} = p_1 + p_2 = p_1^0 x_1 + p_2^0 x_2$$

$$p_{\text{total}} = (1-x_2) p_1^0 + p_2^0 x_2 = p_1^0 + (p_2^0 - p_1^0) x_2$$

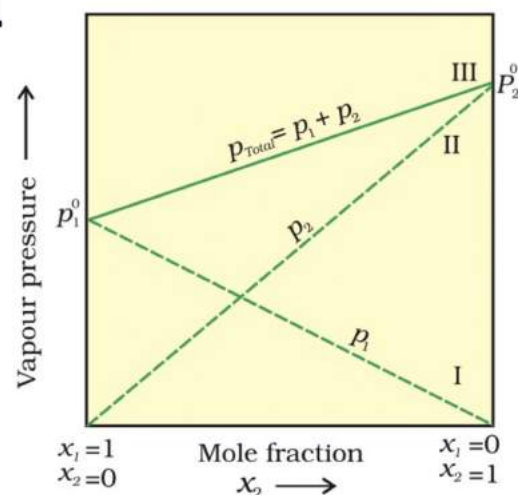
$$[x_1 + x_2 = 1]$$

$$\rightarrow y = mx + c$$

→ Linear graph between total V.P. and x_2 .

→ For line II : $p_{\text{total}} = p_2^0$

Initially $\rightarrow x_1 = 0$
 $x_2 = 1$



→ If y_1 and y_2 are the mole fractions of the liquid-1 and 2 respectively in vapour phase then, using Dalton's law of partial pressures $p_1 = y_1 p_{\text{total}}$

→ At equilibrium, vapour phase will be always rich in the component which is more volatile. $p_2 = y_2 p_{\text{total}}$

Question: The vapour pressure of pure liquids A and B are 450 mm and 700 mm of Hg respectively at 350 K. Find out the composition of the liquid mixture if total vapour pressure is 600 mm of Hg. Also, find the composition in vapour phase? [CBSE 2013C] 3M

Answer:- $P_A^\circ = 450 \text{ mm of Hg}$ $P_B^\circ = 700 \text{ mm of Hg}$
 $P_T = 600 \text{ mm of Hg}$ $x_A / x_B / y_A / y_B ?$

$$\rightarrow P_T = P_B^\circ + (P_A^\circ - P_B^\circ) x_A \Rightarrow 600 = 700 + (450 - 700) x_A$$

$$\text{mole fraction of A in liquid } x_A = \frac{100}{250} = \underline{0.40}$$

$$\text{mole fraction of B in liquid phase } x_B = 1 - x_A = 1 - 0.40 = \underline{0.60}$$

$$\rightarrow P_A = x_A \cdot P_A^\circ = (0.40)(450) = 180 \text{ mm of Hg}$$

$$P_B = x_B P_B^\circ = (0.60)(700) = 420 \text{ mm of Hg}$$

$$P_A = y_A P_T \Rightarrow y_A = \text{mole fraction of A in vapour phase} = \frac{P_A}{P_T} = \frac{180}{600} = \underline{0.30}$$

$$P_B = y_B P_T \Rightarrow y_B = \frac{P_B}{P_T} = \frac{420}{600} = \underline{0.70}$$

Note:- In above question: $y_B > y_A$ [So, vapour phase is more rich in component (B).
 $B \Rightarrow B$ is more volatile liquid than A.]

Raoult's Law as a special case of Henry's Law :- [CBSE 2013 / Delhi 2014] 1M

According to Raoult's law, vapour pressure of volatile component $p = x P^\circ$. — (i)
 in a given solution

→ In the solution of a gas in liquid, if one of the components is so volatile that it exists as a gas is directly proportional to mole fraction: $p = K_H \cdot x$ — (ii)
 then its solubility Henry's law ↗

→ When K_H becomes equal to P° [both are constant for a given liquid at constant temperature]

then, Raoult's law becomes special case of Henry's law.

Ideal and non-ideal solution :- Liquid-liquid solutions can be classified into ideal and non-ideal solutions on the basis of Raoult's law. [Delhi 2013] (2M)

Ideal Solution [Delhi 2017] (1M)
[CSE 2012/2013/2014]

(i) The solutions which obey Raoult's law over entire range of concentration are known as ideal solution.

(ii) $P_A = x_A P_A^\circ$
 $P_B = x_B P_B^\circ$

(iii) Component A + Component B → Solution AB
Forces of attraction between A-B are exactly same as A-A and B-B.

$$F_{A-B} = F_{A-A} = F_{B-B}$$

(iv) On mixing, there is no enthalpy and volume change.

$$\Delta H_{\text{mix}} = 0$$

$$\Delta V_{\text{mix}} = 0$$

Example → n-Hexane and n-Heptane
bromoethane and chloroethane
Benzene and Toluene

Non-ideal Solution

(i) When a solution does not obey Raoult's law over entire range of concentration, then it is called non-ideal solution.

(ii) $P_A \neq x_A P_A^\circ$
 $P_B \neq x_B P_B^\circ$

(iii) Component A + Component B → Component AB (solution)

$$F_{A-B} \neq F_{A-A} \neq F_{B-B}$$

(iv) On mixing, there is enthalpy and volume change.

$$\Delta H_{\text{mix}} \neq 0$$

$$\Delta V_{\text{mix}} \neq 0$$

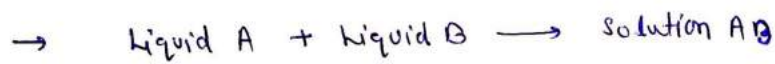
Example → H₂O and ethanol
H₂O and CH₃COOH
CH₄ and CCl₄.

→ Two types of non-ideal solution :

(i) Positive Deviation from Raoult's law :- A-B interactions are weaker than A-A and B-B interactions. Due to this vapour pressure increases which results in positive deviation.

$$(P_{\text{Total}})_{\text{exp}} > (x_A P_A^\circ + x_B P_B^\circ)$$

[Delhi 2015]

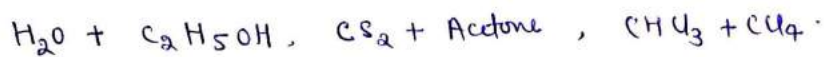


$$\Delta H_{\text{mix}} = \oplus \text{ve}$$

2M

$$\Delta V_{\text{mix}} = \oplus \text{ve}$$

Example—: $\text{H}_2\text{O} + \text{CH}_3\text{OH}$, Ethanol + Acetone



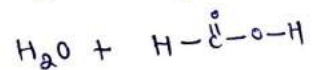
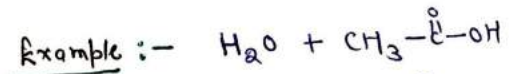
ii) Negative Deviation from Raoult's law— A-B interactions are stronger than A-A and B-B interactions. Due to this, vapour pressure decreases which results in negative deviation.

$$\rightarrow (P_{\text{Total}})_{\text{exp}} < x_A P_A^\circ + x_B P_B^\circ$$

$$\rightarrow \Delta H_{\text{mix}} = \ominus \text{ve} \quad \text{and} \quad \Delta V_{\text{mix}} = \ominus \text{ve}$$

2M

[CBSE 2010/2011]
Delhi 2010

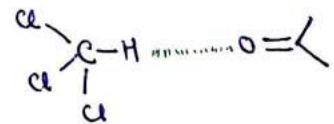


phenol + Aniline



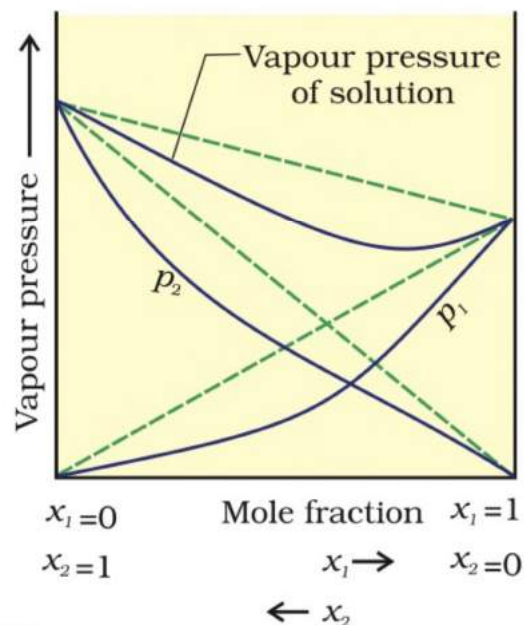
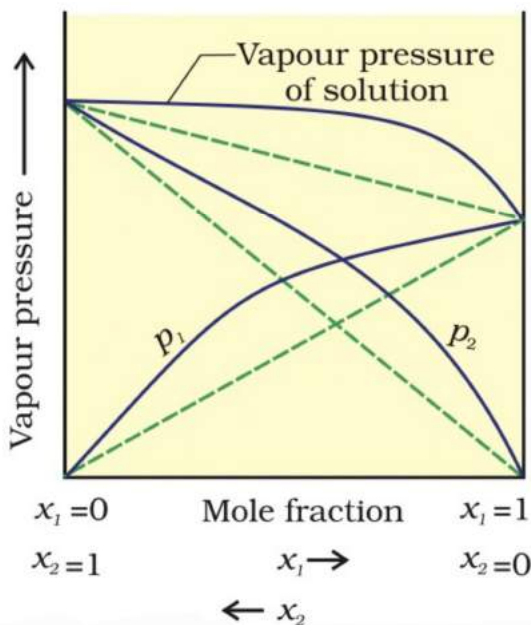
$\rightarrow$ A solution of CHCl_3 [Chloroform] and $\text{CH}_3-\ddot{\text{O}}-\text{CH}_3$ (Acetone) shows $\ominus \text{ve}$ deviation? Why? [Delhi 2011C]

In pure CHCl_3 and pure acetone, there is no hydrogen bonding but after mixing there is hydrogen bonding between hydrogen of CHCl_3 and oxygen of acetone. Due to strong interaction between solution molecules, vapour pressure decreases which results in $\ominus \text{ve}$ deviation.



Azeotropes— Binary mixtures having same composition in liquid and vapour phase and boil at a constant temperature. [$x_A = y_A$ and $x_B = y_B$]

[CBSE 2013]
Delhi 2014/15



→ Azeotropes can't be separated into its components by fractional distillations.

→ There are two types of azeotropes.

(i) Minimum boiling point azeotrope :- The solution which show large positive deviation from Raoult's law form minimum boiling azeotrope at a specific composition

For example: $C_2H_5OH + H_2O$ [with 95% by volume of ethanol]

[Delhi 2015]

1M

(ii) Maximum boiling azeotrope -: The solution that show large negative deviation from Raoult's law form maximum boiling azeotrope at a specific composition.

[CSE 2016]

1M

For example -: $HNO_3 + H_2O$ [68% nitric acid + 32% water by mass]

Colligative Properties

1M

[Delhi 2017]

→ The properties of solutions which depend only on the number of solute particles

→ Colligative Properties $\propto$ No. of particles in solution $\propto \frac{1}{\text{Molar mass of solute}}$

→ Four Colligative properties -: i) Relative lowering of vapour pressure [RLVP]

ii) Depression of freezing point of solvent.

iii) Elevation of boiling point of solvent.

iv) Osmotic pressure of solution.

Relative Lowering of v.p. [RLVP] -

→ When a non-volatile solute is dissolved in a solvent, v.p. of the solution becomes lower than that of pure solvent which is known as RLVP.

→ If x_1 : Mole fraction of solvent and x_2 : mole fraction of solute

then vapour pressure of solution $p = x_1 p^\circ$ [$p^\circ \rightarrow$ v.p. of pure solvent]

The reduction in the v.p. of solvent (Δp) = $p^\circ - p = p^\circ - x_1 p^\circ = (1 - x_1) p^\circ$

$$\Delta p = x_2 p^\circ \Rightarrow \boxed{\text{RLVP } \frac{\Delta p}{p^\circ} = x_2} \quad \text{means that, RLVP} = \frac{\text{mole fraction of solute}}{\text{Solute.}}$$

→ If n_1 and n_2 are number of moles of solvent and solute. Then

$$\text{RLVP} = \frac{p^\circ - p}{p^\circ} = x_2 = \frac{n_2}{n_2 + n_1}$$

→ For dilute solution $n_2 \ll n_1 \Rightarrow$

$$\frac{p^\circ - p}{p^\circ} = \frac{n_2}{n_1} = \left(\frac{w_2}{M_2}\right) \cdot \left(\frac{M_1}{w_1}\right)$$

→ Here w_1 and w_2 are the masses and M_1 and

M_2 are the molar masses of solvent and solute respectively.

Question:- A solution is prepared by dissolving 10 g of non-volatile solute in 200 g of water. It has a vapour pressure of 31.04 mm of Hg at 300 K. Calculate the molar mass of solute. [V.P. of pure water = 32 mm of Hg] [CBSE 2015] (3M)

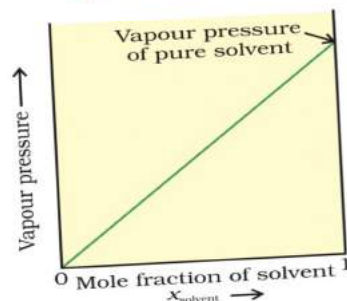
Answer:- $w_2 = 10 \text{ g}$ $w_1 = 200 \text{ g}$ $p = 31.04 \text{ mm of Hg}$

$M_2 = ?$

$M_1 = 18 \text{ g}$

$p^\circ = 32 \text{ mm of Hg}$

H_2O



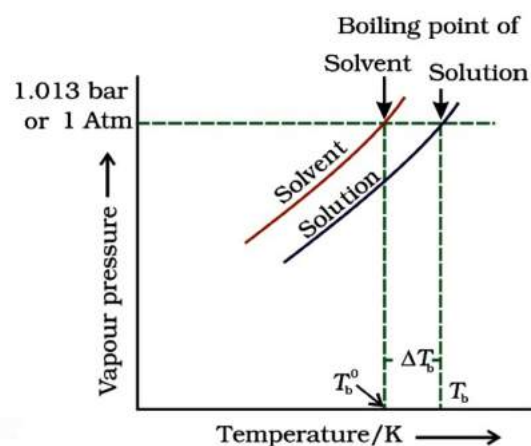
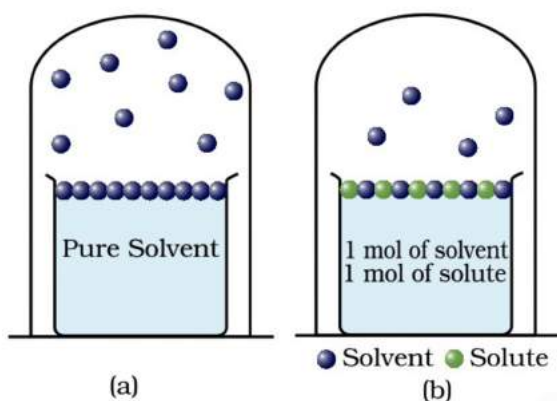
$$\Rightarrow \frac{p^\circ - p}{p^\circ} = \frac{n_2}{n_1} = \frac{(w_2/M_2)}{(w_1/M_1)} \Rightarrow \frac{32 - 31.04}{32} = \frac{(10/M_2)}{(200/18)} \text{ then } M_2 = 100 \frac{\text{g}}{\text{mol}}$$

Elevation of boiling point :-

→ As we know B.P. of a liquid is a temperature at which its v.p. becomes equal to the atmospheric pressure.

→ The B.P. of a solution is always higher than the B.P. of pure solvent in which the solution is prepared. This is because v.p. of solution at a given temperature is found to be lower than v.p. of pure solvent at the same temperature.

→ In a pure liquid the entire surface is occupied by the molecules of liquid. If a non-volatile solute is added to pure liquid to give a solution. Then surface has both solute and solvent molecules, so the fraction of surface covered by solvent molecules gets reduced. So the no. of solvent molecules escaping from surface is reduced. Thus the v.p. is also reduced. [Delhi 2014c] (2M)



→ If T_b° is B.P. of pure solvent and T_b is the B.P. of solution, then elevation in B.P. $\Delta T_b = T_b - T_b^\circ$

→ For dilute solutions $\Delta T_b \propto m$

[CBSE 2012] 1

$$\Delta T_b = K_b \cdot m$$

[Here m is molality or molar concentration of solute in a solution.]

[K_b : B.P. elevation constant / Molar elevation constant]

→ As unit of $m = \frac{\text{mol}}{\text{kg}}$, so, unit of $K_b = \text{K kg mol}^{-1}$.

If W_2 g of solute of molar mass M_2 is dissolved in W_1 g of solvent, then molality of solution $m = \frac{(W_2/M_2) \text{ mole}}{(W_1/1000) \text{ kg}}$

Then;

$$\Delta T_b = K_b \cdot \frac{1000 W_2}{M_2 \cdot W_1}$$

and Molar mass of solute

$$M_2 = \frac{1000 W_2 \cdot K_b}{\Delta T_b \cdot W_1}$$

Questions :- 10 g of glucose (molar mass = 180 g mol^{-1}) is dissolved in 1 kg of water in a sauce pan. At what temperature will this solution boil?

(K_b for water = $0.52 \text{ K kg mol}^{-1}$, B.P. of pure water = 373.15 K)

2M

[Delhi 2013]

Answer :- $W_1 = 1 \text{ kg} = 1000 \text{ g}$

$$T_b^\circ = 373.15$$

$$W_2 = 10 \text{ g}$$

$$K_b = 0.52 \text{ K kg mol}^{-1}$$

$$M_2 = 180 \text{ g mol}^{-1}$$

$$\Delta T_b = K_b \cdot m = K_b \cdot \frac{1000 W_2}{M_2 \cdot W_1} = 0.52 \times \frac{1000 \times 10}{180 \times 1000} = 0.052 \text{ K}$$

$$\rightarrow \Delta T_b = T_b - T_b^\circ = T_b - 373.15 = 0.052 \text{ K}$$

$$T_b = 373.15 + 0.052 = 373.202 \text{ K}$$

$$T_b = 373.2 \text{ K}$$

Question :- A solution of glycerol [$\text{C}_3\text{H}_8\text{O}_3$] in water was prepared by dissolving some glycerol in 500 g of water. This solution has a B.P. of 100.42°C , what mass of glycerol was dissolved to make this solution?

$$K_b \text{ for water} = 0.512 \text{ K kg mol}^{-1}$$

3M

[CBSE 2012
Delhi 2012/2010]

Answer → $M_2 = 92 \text{ g mol}^{-1}$ $W_1 = 500 \text{ g}$ $W_2 = ?$ $K_b = 0.512 \text{ K kg mol}^{-1}$

$$\Delta T_b = T_b - T_b^\circ = 100.42^\circ\text{C} - 100^\circ\text{C} = 0.42 \text{ K}$$

$$\rightarrow \Delta T_b = K_b \left(\frac{W_2}{M_2} \right) \times \left(\frac{1000}{W_1} \right) \Rightarrow 0.42 = 0.512 \left(\frac{W_2}{92} \right) \left(\frac{1000}{500} \right)$$

$$W_2 = 37.73 \text{ g} = \text{mass of glycerol dissolved.}$$

Depression of freezing point —:

- The freezing point of a substance is the temperature at which v.p. of the substance in its liquid phase is equal to its v.p. in solid phase.
- When a non-volatile solute is added to a solvent, the freezing point of the solution is always lower than that of pure solvent, as v.p. of solvent decreases in presence of non-volatile solute. [Delhi 2013C]

- This difference in freezing point is known as Depression in freezing point.

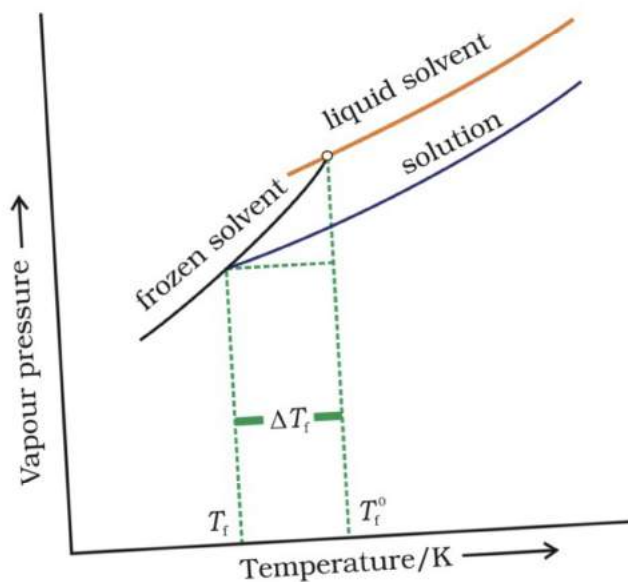
$$\Delta T_f = T_f^\circ - T_f$$

Freezing point of pure solvent Freezing point of solution.

$$\rightarrow \Delta T_f \propto m$$

$$\Delta T_f = K_f m$$

$$\Delta T_f = K_f \times \frac{W_2 (M_2)}{(W_1 / 1000)}$$



K_f → Freezing Point Depression constant.
 ↳ Molal Depression constant.
 ↳ Cryoscopic constant.

Question :- Calculate the freezing point of a solution containing 60 g of glucose (molar mass = 180 g mol^{-1}) in 250 g of water. (K_f of water = $1.86 \text{ K kg mol}^{-1}$) [Delhi 2018]

Answer :- $W_2 = 60 \text{ g}$ $M_2 = 180 \text{ g mol}^{-1}$ $W_1 = 250 \text{ g}$ (2M)

$$\text{molality of solution} \Rightarrow m = \left(\frac{W_2}{M_2} \right) \times \frac{1000}{W_1} \Rightarrow \frac{60 \text{ g}}{180 \text{ g mol}^{-1}} \times \frac{1000}{250 \text{ g mol}^{-1}}$$

$$m = 1.33$$

$$\Delta T_f = K_f \cdot m = 1.86 \times 1.33 = 2.47 \text{ K}$$

$$T_f^\circ - T_f = 2.47 \text{ K}$$

$$[\text{Freezing point of pure water} = 273.15 \text{ K} = 0^\circ \text{C}]$$

$$\begin{aligned} \text{Freezing point of solution } (T_f) &= 273.15 - 2.47 \\ &= \underline{270.68 \text{ K}} \end{aligned}$$

Question :- Calculate the mass of compound (molar mass = 256 g mol^{-1}) to be dissolved in 75 g of benzene to lower its freezing point by 0.48 K .
($K_f = 5.12 \text{ K kg mol}^{-1}$). [CBSE 2014] (2M)

Answer :- $W_1 = 75 \text{ g}$ $\Delta T_f = 0.48 \text{ K}$ $M_2 = 256 \text{ g mol}^{-1}$
 $K_f = 5.12 \text{ K kg mol}^{-1}$

$$\rightarrow \Delta T_f = K_f \cdot m = \frac{K_f \cdot W_2 \cdot 1000}{W_1 \cdot M_2} \Rightarrow 0.48 = \frac{5.12 \times W_2 \times 1000}{75 \times 256}$$

$$W_2 = \text{mass of solute} = 1.8 \text{ g}$$

Question :- A 10% solution (by mass) of sucrose in water has freezing point of 269.15 K . Calculate freezing point of 10% glucose in water. If freezing point of pure water is 273.15 K .
[Delhi 2017] (3M)
[Given : molar mass of sucrose = 342 g mol^{-1} ; Molar mass of glucose = 180 g mol^{-1}]

Answer :- 10% solution by mass means 10 g of sucrose dissolved in 90 g of water.

$$\rightarrow W_2 = 10 \text{ g} \quad W_1 = 90 \text{ g} \quad M_2 = 342 \text{ g mol}^{-1}$$

$$\text{then molality } m = \frac{(W_2 / M_2)}{(W_1 / 1000)} = \frac{(10 / 342)}{(90 / 1000)} = 0.324 \text{ mol kg}^{-1}$$

$$\Delta T_f = T_f^\circ - T_f = 273.15 - 269.15 = 4 \text{ K}$$

$$\rightarrow \Delta T_f = K_f \cdot m \Rightarrow K_f = \frac{\Delta T_f}{m} = \frac{4}{0.324} \quad (K_f \text{ is constant (same) for solvent (water)})$$

For glucose solution : $W_2 = 10 \text{ g}$ $W_1 = 90 \text{ g}$ $M_2 = 180 \text{ g mol}^{-1}$

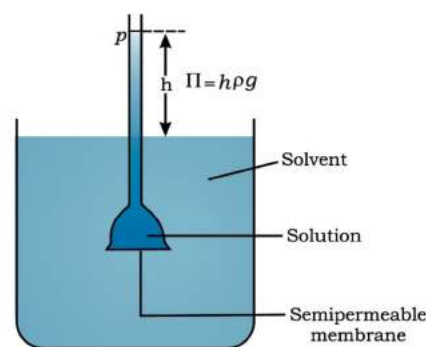
$$\rightarrow \Delta T_f = K_f \cdot m \Rightarrow \left(\frac{4}{0.324} \right) \times 0.617 = 7.617 \text{ K}$$

$$\text{Hence, Freezing point of glucose solution} = 273.15 - 7.617 = \underline{265.53 \text{ K}}$$

$$m = 0.617 \frac{\text{mol}}{\text{kg}}$$

Osmosis and Osmotic pressure :- The process of flow of solvent molecules from solution of lower concentration to solution of higher concentration through semipermeable membrane is known as Osmosis. [CBSE 2013, Delhi 2015C | 2011] (1M)

- The hydrostatic pressure which develops on account of osmosis is called Osmotic pressure.
- The pressure which just stops the flow of solvent is called Osmotic pressure of solution.



→ Osmotic pressure $\propto$ Molarity (C)
(π)

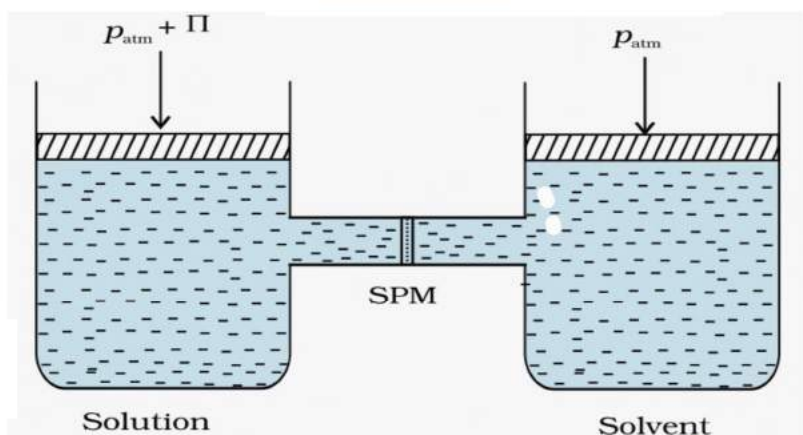
$$\pi = CRT = \frac{n_2}{V} RT$$

→ Here, $V \rightarrow$ volume of solution (in L)

$n_2 \rightarrow$ Mols of solute ($= \frac{W_2}{M_2}$)

$$\pi = \frac{(W_2/M_2)}{V} RT$$

→ $M_2 = \frac{W_2 RT}{\pi V}$ → Osmotic pressure is used to determine molar masses of macromolecules like proteins, polymers. [Delhi 2015C] (2M)



Question :- A solution prepared by dissolving 0.95 mg of a gene fragment in 35 ml of water has an osmotic pressure of 0.335 torr at 25°C. Assuming the gene fragment is non-electrolyte, determine its molar mass. [CBSE 2011] (3M)

Answer :- $W_2 = 0.95 \text{ mg} = 0.95 \times 10^{-3} \text{ g}$

$$V = 35 \text{ ml} = \frac{35}{1000} \text{ L}$$

$$\pi = 0.335 \text{ torr} = \frac{0.335}{760} \text{ atm}$$

$$T = 273 + 25 = 298 \text{ K}$$

$$\pi = CRT = \frac{(W_2/M_2)}{V} RT$$

$$\text{then } M_2 = \frac{W_2 RT}{\pi V} = \frac{(0.95 \times 10^{-3})(0.082)(298)}{\left(\frac{0.335}{760}\right)\left(\frac{35}{1000}\right)}$$

$$\rightarrow M_2 = 1.417 \times 10^4 \text{ g mol}^{-1}$$

Question :- At 300K, 36 g of glucose (molar mass = 180 g mol⁻¹) present per litre in its solution has an osmotic pressure of 4.98 bar. If the osmotic pressure of another glucose solution is 1.52 bar at the same temperature. Calculate the concentration of other solution? [similar question in 2019] [CBSE 2011C] (3M)

$$\rightarrow \pi = CRT = \frac{W_2 RT}{M_2 V}$$

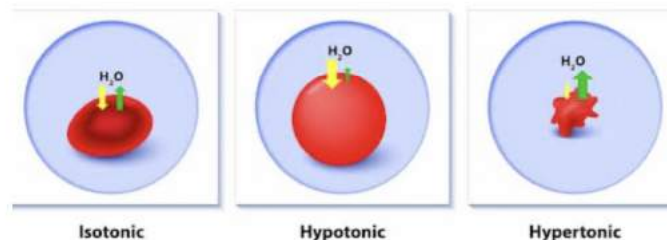
$$\text{For first solution : } 4.98 \text{ bar} = \frac{(368) RT}{(100 \text{ g mol}^{-1}) \cdot V} \quad \text{--- (1)}$$

$$\text{For second solution : } 1.52 \text{ bar} = \frac{W_2 RT}{M_2 V} \quad \text{--- (2)}$$

Dividing (2) by (1) :-

$$\frac{1.52}{4.98} = \frac{W_2 RT}{M_2 V} \times \frac{100 V}{368 RT}$$

$$\frac{W_2}{M_2} = 0.061 \text{ mol}$$



Question :- Define the following terms ?

(i) Isotonic solutions :- Two solutions having same osmotic pressure at a given temperature are called isotonic solutions. [Delhi 2012 | CBSE 2012]

(ii) A solution having lower osmotic pressure than other solution is called hypotonic while a solution having higher osmotic pressure is called hypertonic.

Example → The osmotic pressure associated with the fluid inside the blood cell is equivalent to that of 0.9% (m/v) NaCl solution, called normal saline solution and it is safe to inject intravenously.

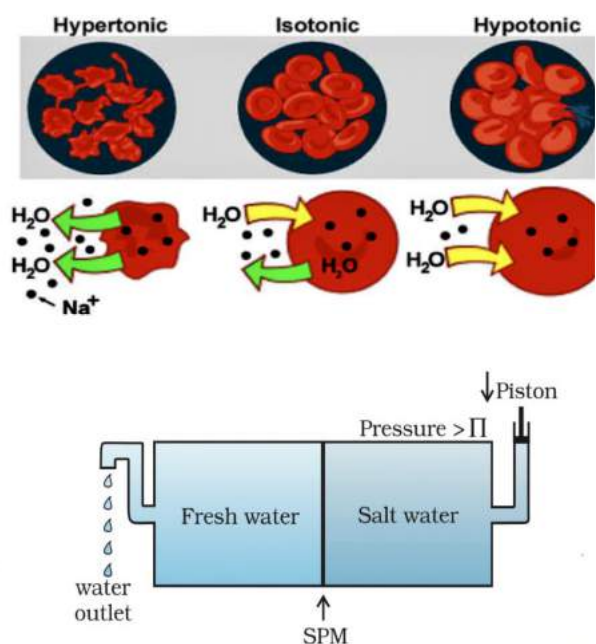
→ If we place the cells in a solution containing more than 0.9% (m/v) NaCl, water will flow out of the cells and they would shrink. Such a solution is called **hypertonic**.

→ If the salt concentration is less than 0.9% (m/v), the solution is said to be **hypotonic**. In this case, water will flow into the cells if placed in this solution and they would swell.

[CBSE 2011 | 2013]

Reverse Osmosis :- If a pressure larger than the osmotic pressure is applied to the solution side, then the pure solvent flows out of solution through semipermeable membrane. This phenomenon is called reverse osmosis [RO].

→ Reverse osmosis is used in desalination of sea water.



Reverse osmosis occurs when a pressure larger than the osmotic pressure is applied to the solution.

Important PYQ's

(i) → The molecular masses of polymers are determined by osmotic pressure method and not by measuring other colligative properties. Give 2 reasons? [Delhi 2018 | CBSE 2011C | 2010] 2M

Answer:- The osmotic pressure method has the advantage over other colligative properties because

1. Pressure measurement is around the room temperature and the molarity of the solution is used instead of molality.
2. Its magnitude is large as compared to other colligative properties even for very dilute solutions.

(ii) → Outer hard shells of two eggs are removed. One of the egg is placed in pure water and the other egg is placed in saturated solution of NaCl . What will be observed and why?

Answer:- The egg placed in water will swell because the concentration of proteins is high inside the egg as compared to water. Therefore, water diffuses through semipermeable membrane of egg and egg swells.

→ The egg placed in NaCl solution will shrink due to osmosis, water will move out of the egg membrane, thereby, shrinking the egg. [CBSE 2010C] 2M

(iii) → A 5% solution (by mass) of cane sugar ($M_w = 342 \text{ g mol}^{-1}$) is isotonic with 0.877% solution of substance X. Find the molecular weight of X. 3M [CBSE 2015C]

Answer:- $W_{\text{cane sugar}} = 5 \text{ g}$

$$W_X = 0.877 \text{ g}$$

$$M_{\text{cane sugar}} = 342 \text{ g mol}^{-1}$$

$$M_X = ?$$

→ Isotonic means same osmotic pressure

$$\pi_{\text{cane sugar}} = \pi_X$$

$$\Rightarrow C_{\text{cane sugar}} \cdot RT = C_X \cdot RT$$

$$\Rightarrow \frac{(W_{\text{cane sugar}} / M_{\text{cane sugar}})}{V} = \frac{(W_X / M_X)}{V}$$

$$\Rightarrow (5 / 342) = \frac{0.877}{M_X} \quad \text{then } \underline{M_X = 59.9 \text{ g mol}^{-1}}$$

Isotonic



Amount of water transported into the cell equal to the amount of water transported out from the cell

Solute concentration inside the cell is Equal to the solution outside the cell

(iv) → Out of 1M glucose and 2M glucose, which one has a higher boiling point and why?
→ 2M glucose has higher B.P. because more the concentration, more is the elevation in boiling point. 1M [Delhi 2016]

Abnormal Molar Mass :- For the substances undergoing association or dissociation in solution, molecular mass determined from colligative properties is different [either lower or higher] from expected value.

→ This experimentally determined molar mass is known as abnormal molar mass.

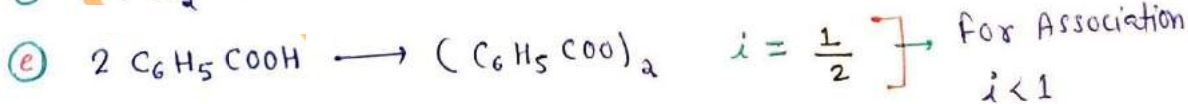
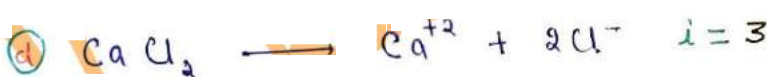
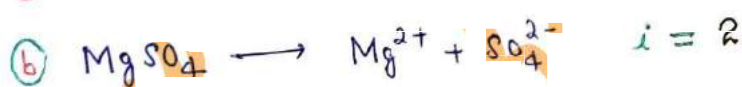
Van't Hoff Factor :- It is the ratio of the experimental value of colligative property to the calculated value of the colligative property.

$$\text{Van't Hoff Factor } [i] = \frac{\text{Normal Molar Mass}}{\text{Abnormal Molar Mass}}$$

$$= \frac{\text{Observed / Experimental colligative property}}{\text{Calculated colligative property}}$$

$$= \frac{\text{Total no. of moles of particles after association / dissociation}}{\text{Number of moles of particles before association / dissociation}}$$

For Example :-



→ For Dissociation
 $i > 1$

→ For Association
 $i < 1$

Dissociation :- Let the degree of dissociation is α for A_xB_y .



$$t=0 : \quad c \qquad 0 \qquad 0$$

$$t_{eq} : \quad c(1-\alpha) \qquad x\alpha \qquad y\alpha$$

Total concⁿ at equilibrium

$$= c(1-\alpha) + x\alpha + y\alpha$$

$$= c[1 + (n-1)\alpha]$$

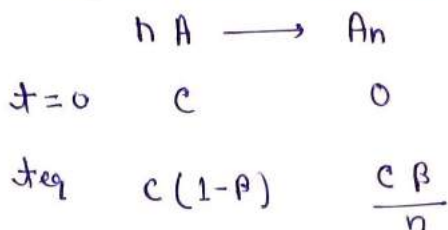
$$i = \frac{c[1 + (n-1)\alpha]}{c}$$

No. of particles after diss. = $n = x+y$
of one molecule of electrolyte

Then;

$$i = 1 + (n-1)\alpha$$

Association :-



$\beta \rightarrow$ Degree of association

For Dimerisation $n=2$

$$\rightarrow i = \frac{C(1-\beta) + \frac{C\beta}{n}}{C} \Rightarrow \boxed{i = 1 + \left(\frac{1}{n} - 1\right)\beta}$$

NOTE :- Modification in equations for colligative properties.

i) RLVP of solvent $\frac{P^\circ - P}{P^\circ} = i \frac{n_2}{n_1}$

ii) Elevation of B.P. $\Delta T_b = i K_b m$

iii) Depression of freezing point $\Rightarrow \Delta T_f = i K_f m$

iv) Osmotic pressure of solution $\pi = i \frac{n_2}{V} RT$

Question :- A 1 molal aq. solution of trichloroacetic acid is heated to its B.P. The solution has B.P. 100.18°C . Determine van't Hoff factor for CCl_3COOH . $K_b(\text{water}) = 0.512 \text{ K kg mol}^{-1}$ [Delhi 2012] (2M)

Answer :- $m = 1$, $K_b = 0.512 \text{ K kg mol}^{-1}$, $T_b = 100.18^\circ\text{C}$

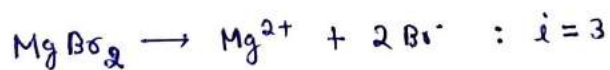
$$\Delta T_b = T_b - T_b^\circ = 100.18 - 100 = 0.18^\circ\text{C}$$

$$T_b^\circ(\text{water}) = 100^\circ\text{C}$$

$$\rightarrow \Delta T_b = i K_b m \Rightarrow 0.18 \text{ K} = i \times 0.512 \times 1 \text{ then } i = 0.35$$

Question :- Calculate the freezing point of an aqueous solution containing 10.5 g of magnesium bromide in 200 g of water, assuming complete dissociation of MgBr_2 . [Molar mass of $\text{MgBr}_2 = 184 \text{ g mol}^{-1}$, $K_f(\text{water}) = 1.86 \text{ K kg mol}^{-1}$] [CBSE 2010C] (3M)

Answer :- $W_2 = 10.5 \text{ g}$, $W_1 = 200 \text{ g}$, $M_2(\text{MgBr}_2) = 184 \text{ g mol}^{-1}$, $K_f = 1.86 \text{ K kg mol}^{-1}$



$$\rightarrow \Delta T_f = i K_f \cdot m = i K_f \left[\frac{W_2 \times 1000}{M_2 \times W_1} \right] = 3 \times 1.86 \left[\frac{10.5 \times 1000}{184 \times 200} \right] = 1.592 \text{ K}$$

$$\rightarrow \text{Freezing point of solution} = T_f^\circ - \Delta T_f = 273 \text{ K} - 1.592 \text{ K} = 271.408 \text{ K}$$

Question :- Phenol associates in benzene to a certain extent to form a dimer. A solution containing 20 g of phenol in 1 kg of benzene has its freezing point lowered by 0.69 K . Calculate the fraction of phenol that has dimerised. [Delhi 2011C] (3M)

$$K_f(\text{benzene}) = 5.1 \text{ K kg mol}^{-1}$$

Answer:- For dimer on association $n=2$. $W_2 = 20g$ $W_1 = 1kg = 1000g$

$$\rightarrow \Delta T_f = K_f \frac{W_2 \times 1000}{M_2 \times W_1}$$

$$\Delta T_f = 0.69K, K_f = 5.1 K kg mol^{-1}$$

$$M_2 = (5.1) \frac{20 \times 1000}{(0.69) \times 1000} = 147.82 g mol^{-1} \Rightarrow \text{Experimental molar mass}$$

$\rightarrow$ calculated molar mass of phenol $[C_6H_5OH] = 6 \times 12 + 6 \times 1 + 16 = 94 g mol^{-1}$

$$i = \frac{M_2 (\text{calculated})}{M_2 (\text{Experimental})} = \frac{94}{147.82} = 0.635$$

$\rightarrow 2 C_6H_5OH \rightleftharpoons (C_6H_5OH)_2$ Degree of association β then

$$i = 1 + \left(\frac{1}{n} - 1\right) \beta$$

$$\Rightarrow \beta = \frac{i-1}{\left(\frac{1}{n} - 1\right)} = \frac{(0.635-1)}{\left(\frac{1}{2} - 1\right)} = 0.73 \Rightarrow \boxed{\beta = 73\%}$$

Question:- An aq. solution containing 12.48 g of $BaCl_2$ in 1 kg of water at 373.0032 K. Calculate the degree of dissociation of $BaCl_2$.

[Given, $K_b(H_2O) = 0.52 K kg mol^{-1}$, molar mass of $BaCl_2 = 208.34 g mol^{-1}$] 3M

Answer:- $W_2 = 12.48g$, $W_1 = 1000g$, $T_b(\text{solution}) = 373.0032K$ [Delhi 2011C]

$$K_b(H_2O) = 0.52 K kg mol^{-1}, M_2 = 208.34 g mol^{-1}$$

$$\rightarrow \Delta T_b = K_b \frac{W_2 \times 1000}{M_2 \times W_1}$$

calculated
Molar mass

$$\Delta T_b = T_b - T_b^\circ = 373.0032 - 373 = 0.0032K$$

$$\rightarrow M_2 = \frac{K_b W_2 \times 1000}{\Delta T_b \times W_1} = \frac{(0.52) (12.48) \times 1000}{(0.0032) \times 1000} = 78 g mol^{-1} = \text{Experimental molar mass}$$

$$i = \frac{M_2 (\text{calculated})}{M_2 (\text{Experimental})} = \frac{208.34}{78} = 2.67$$

For $BaCl_2 \rightarrow Ba^{+2} + 2Cl^{-}$

$$i = 1 + (n-1)d$$

$n=3$

$$\text{Degree of dissociation } d = \frac{i-1}{n-1} = \frac{2.67-1}{3-1} = 0.835$$

$$\boxed{d = 83.5\%}$$