SOLUTIONS

by Apni Kaksha :)

Class XII BOARD EXAMS (Target 100)

These notes have been verified by CBSE Science Toppers.

Previous 15 year Questions have been integrated in the notes.

Aman Dhattarwal

HOW TO STUDY THE NOTES?

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-Coloured and double sided print
- Revise the notes at least 3-4 time
- Write to revise | 10% rule
- Keep track of previous year qs
- See the marking scheme

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

⊖ve Deviation

Azeotrope

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

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

→ 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 $x_A = \dfrac{n_A}{n_A + n_B}$.

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

→ 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 component.

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

(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.

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(iii) → Volume Percentage [V/V] —:

$$\text{Volume \% of a Component} = \frac{\text{Volume of the Component}}{\text{Total volume of Solution}}$$

→ 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 pecentage [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]

$$\text{Parts per million} = \frac{\text{No. of parts of Component}}{\text{Total no. of parts of all Components}} \times 10^6$$
of the Solution.

→ 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).

→ $\% \frac{W}{V} = \frac{\text{Weight of solute (g)}}{\text{Volume of solution (ml)}} \times 100$ similarly; $PPM\left(\frac{W}{V}\right) = \frac{\text{Weight of Solute (g)}}{\text{Volume of Sol}^n \text{(ml)}} \times 10^6$

Per cent

→ 5.0 PPM O_2 is dissolved in sea —: means 5.0 g of 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 80 g of water.

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

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

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

→ mole fraction of glycol $x_{glycol} = \dfrac{n_{glycol}}{n_{glycol} + n_{water}} = \dfrac{0.322}{0.322 + 4.444} = 0.068$

→ Similarly $x_{water} = 1 - x_{glycol} = 1 - 0.068 = 0.932$

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

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

$\boxed{\begin{array}{c} CBSE\,2015\,C \\ Delhi\,2014\,C \\ \hline 2011 \end{array}}$

$\boxed{1M}$

→ Unit —: mol/ litre [M]

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

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

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

$= 0.45$ L

Molarity $= \dfrac{0.125 \text{ mol}}{0.45 \text{ L}} = 0.278$ mol $L^{-1} = 0.278$ 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 = 100 g mol^{-1}]   [CBSE 2013] $\boxed{2M}$

Answer —: 10 % glucose solution by weight means 10 g glucose is present in 100 g solution

Then weight of water = 100 − 10 = 90 g

Molality $= \dfrac{\text{Moles of solute}}{\text{Mass of solvent (kg)}} = \dfrac{(10/100) \text{ mol}}{\left(\dfrac{90}{1000}\right) \text{kg}} = 0.61$ mol $kg^{-1} = 0.61$ m.

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

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

→ 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 = $CH_3 - COOH$ = $12 \times 2 + 1 \times 4 + 16 \times 2 = 60\ g\ mol^{-1}$

$$Molality\ of\ CH_3COOH = \frac{Moles\ of\ CH_3COOH}{kg\ of\ benzene} = \frac{(2.5/60)}{(75/1000)} = 0.556\ \frac{mol}{kg}.$$

★ **Main advantage of molality over molarity :—** Molality does not change with change in temperature while, molarity decreases with rise in temperature. This is because volume depends on temperature ($V \propto T$) but mass does not. [Delhi 2014C/2011, 2010] (1M)

→ **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 $$Molality\ m = \frac{M \times 1000}{1000 \times d - M \times M_2}$$ (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 $H_2SO_4 \rightarrow 98\ g\ mol^{-1}$

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 = $\frac{Mass\ of\ Solution}{Density\ of\ Solution}$

→ Moles of $H_2SO_4 = \frac{9.8\ g}{98\ g\ mol^{-1}} = 0.1\ mol$

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

→ Molarity $= \frac{0.1\ mol}{0.098\ L} = 1.019 = 1.02\ M$ mol L⁻¹

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 → 1.2 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 = $\dfrac{m}{d} = \dfrac{100g}{1.2 \, g \, ml^{-1}} = \dfrac{1000}{12} \, ml$

$= \dfrac{1}{12}$ Litre

Molar mass of glucose

$=$

$\dfrac{100 \, g}{mol}$

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

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

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Solubility

→ Solubility of a substance is its maximum amount that can be dissolved in a fix abount 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.   Solute + Solvent ⇌ Solution

→ At this dyamic 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 ↑ of temperature ⟹ solubility ↑.

→ For exothermic ($\Delta H < 0$) then on ↑ of temperature ⟹ solubility ↓.

→ 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   (iii) 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]
(1M)

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

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

Henry's Law Constant

Henry 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 ⟹ $K_H \propto \frac{1}{x}$.
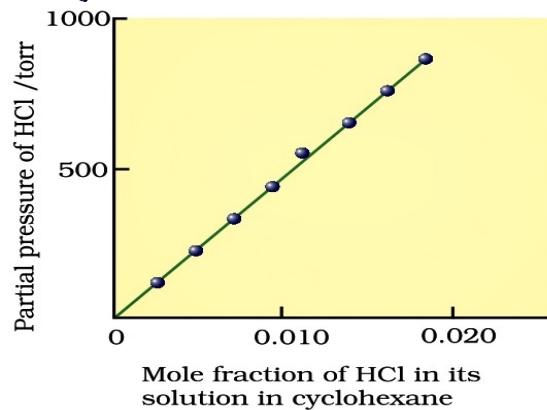
(iii) Unit of K_H = Unit of pressure = atm/torr

Henry's Law Constant

y-axis: Partial pressure of HCl /torr — 1000, 500, 0

x-axis: 0, 0.010, 0.020 — Mole fraction of HCl in its solution in cyclohexane

⟹ K_H is proportional to temperature. [$K_H \propto T$ and $K_H \propto \frac{1}{x}$ ⟹ $T \propto \frac{1}{x}$]
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 / 2019C]
                          [Delhi 2012C]
(2M) ---↗

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, symtoms of a condition known as anoxia.

[CBSE 2019]
(1M)
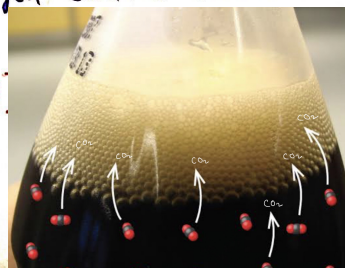
Question :- The partial pressure of ethane over a saturated solution containing 6.56×10^{-2} g of ethane is 1 bar. If solution contains 5.0×10^{-2} g of ethane, then what will be partial pressure of the gas?

$$\begin{bmatrix} \text{CBSE 2012C} \\ \text{Delhi 2011C} \end{bmatrix} \quad \text{(3M)}$$

Answer-: According to Henry's Law -:

① mass of ethane $\propto$ partial pressure $\quad [m_1 = K_H \cdot P_L]$

$$6.56 \times 10^{-2} g = K_H \cdot 1 \, bar \quad —①$$

⑪ $\quad m_2 = K_H \, P_2$

$$\Downarrow$$

$$K_H = \frac{6.56 \times 10^{-2} \, g}{bar}$$

partial pressure of gas $(P_2) = \frac{m_2}{K_H} = \frac{5 \times 10^{-2} g}{\frac{6.56 \times 10^{-2} g}{bar}} = 0.762 \, bar.$

Question :— If N_2 gas is bubbled through water at 293 k, how many millimoles of N_2 gas would dissolve in 1L of water? Assume that N_2 exerts a partial pressure of 0.987 bar. given → $K_H = 76.48$ Kbar at 293 k. $\quad$ [CBSE 2012C] (3M)

Answer —: According to Henry's Law —: $\quad P_{N_2} = K_H \cdot x_{N_2}$

$$x_{N_2} = \frac{P_{N_2}}{K_H} = \frac{0.987 \, bar}{76.48 \times 10^3 \, bar} = 1.29 \times 10^{-5}$$

→ If n moles of N_2 are present in

1L or 1000 g of water then moles of

$$water = n_{water} = \frac{1000}{18} = 55.5 \, moles \quad [H_2O = 16+2 \times 1]$$

→ Mole fraction of $N_2 = \frac{n}{n + n_{water}} = \frac{n}{55.5} \quad [n <<<< n_{water}]$

$$x_{N_2} \cdot (55.5) = n \implies n = 55.5 \times 1.29 \times 10^{-5} = 71.595 \times 10^{-5} \, moles$$

$$n = 0.716 \times [10^{-3} \, moles] = 0.716 \, milimoles$$

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 -: $H_2O(l) \rightleftharpoons H_2O(g) \quad$ Equilibrium constant $(K_P) = \frac{P_{H_2O(g)}}{P_{H_2O(l)}}$

for pure $H_2O(l)$: $P_{H_2O(l)} = 1 \quad$ then $\boxed{K_P = P_{H_2O(g)}}$

→ for liquid ⇌ Vapours : Vapour pressure is an equilibrium constant. So it depends only on ⓐ Nature of liquid ⓑ Temperature of liquid.

→ If 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.

→ <u>Boiling Point</u> –: The temperature at which vapour pressure of a liquid is equal to external pressure.

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

<u>vapour pressure of liquid - liquid solutions :–</u>

<u>Raoult's Law</u> :– 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 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.
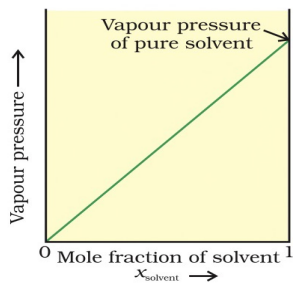
for liquid-1 : $p_1 \propto x_1$

$p_1 = p_1^o x_1$ ——ⓘ

$p_1^o \to$ vapour pressure of pure liquid 1

→ For liquid-2 : $p_2 \propto x_2$

$p_2 = p_2^o x_2$ ——ⓘⓘ

$p_2^o \to$ vapour pressure of pure liquid 2.

Vapour pressure vs Mole fraction of solvent ($x_{solvent}$) — Vapour pressure of pure solvent

(1M) $\begin{bmatrix} CBSE\ 2011\ |\ 2013 \\ Delhi\ 2011\ |\ 2010C\ |\ 2013\ |\ 2014 \end{bmatrix}$

→ 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.
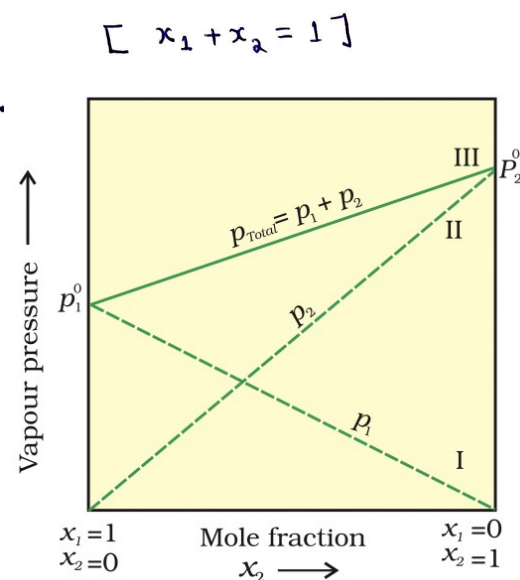
$p_{total} = p_1 + p_2 \quad = p_1^o x_1 + p_2^o x_2$

$[x_1 + x_2 = 1]$

$p_{total} = (1-x_2) p_1^o + p_2^o x_2 = p_1^o + (p_2^o - p_1^o) x_2$

→ $y = mx + c$

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

→ $\boxed{\text{for line II}}$: $p_{total} = p_2^o$

Initially → $x_1 = 0$

$x_2 = 1$

Vapour pressure vs Mole fraction x_2; $p_{Total} = p_1 + p_2$; p_1^o, p_2^o; lines I, II, III

→ 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 $p_1 = y_1 \, p_{total}$

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

Question : The vapour pressure of pure liquids A and B are 450 mm and 700 mm of Hg respectively at 350K. 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 :- $P_A^\circ = 450$ mm of Hg $P_B^\circ = 700$ mm of Hg

$P_T = 600$ mm of Hg $x_A \mid x_B \mid y_A \mid y_B$?

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

mole fraction of A in liquid $x_A = \dfrac{100}{250} = \underline{0.40}$ → Composition in liquid.

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

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

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

$P_A = y_A \, P_T$ ⟹ $y_A =$ mole fraction of A in vapour phase $= \dfrac{P_A}{P_T} = \dfrac{180}{600} = \underline{0.30}$

$P_B = y_B \, P_T$ ⟹ $y_B = \dfrac{P_B}{P_T} = \dfrac{420}{600} = \underline{0.70}$

Note :- In above question : $y_B > y_A$ $\left[\begin{array}{l}\text{So, vapour phase is more rich in component (liq.)}\\ B \Rightarrow B \text{ is more volatile liquid than A.}\end{array}\right]$

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 $p = x \, p^\circ$. —①
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 : $p = K_H \cdot x$ —②
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 1019] (2M)

Ideal Solution [Delhi 2017] (1M) 2010c
[CBSE 2012/2013/2014]

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

(ii)→ $P_A = x_A P_A°$

$P_B = x_B P_B°$

(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. $\Delta H_{mix} = 0$

$\Delta V_{mix} = 0$

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)→ $P_A \neq x_A P_A°$

$P_B \neq x_B P_B°$

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

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

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(iv) On mixing, there is enthalpy and volume change. $\Delta H_{mix} \neq 0$
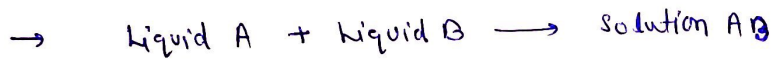
$\Delta V_{mix} \neq 0$

Example → H_2O and ethanol

H_2O and CH_3COOH

CHU_3 and CCl_4.

→ 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.

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

$\rightarrow$ Liquid A + Liquid B $\longrightarrow$ Solution AB $\Delta H_{mix} = \oplus ve$

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

Example—: $H_2O + CH_3OH$, Ethanol + Acetone

$H_2O + C_2H_5OH$, CS_2 + Acetone , $CHCl_3 + CCl_4$.
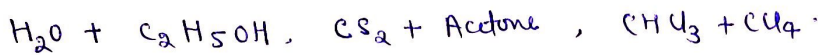
(ii) **Negative Deviation from Raoult's Law** :—   A—B interactions are stronger than A—A and B—B interactions. Due to this, vapour pressure decreases which results in negative deviation.

$\rightarrow$ $(P_{Total})_{exp} < x_A P^° + x_B P^°$

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

Example :— $H_2O + CH_3-\overset{\overset{O}{\parallel}}{C}-OH$

$H_2O + H-\overset{\overset{O}{\parallel}}{C}-O-H$
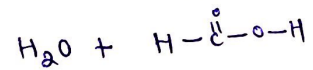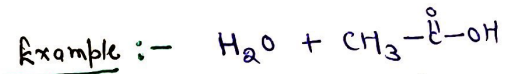
phenol + Aniline

$CHCl_3$ + Acetone.

$\rightarrow$ A solution of $CHCl_3$ [Chloroform] and $CH_3-\overset{\overset{O}{\parallel}}{C}-CH_3$ (Acetone) shows $\ominus ve$ deviation ? Why.

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 $\ominus ve$ deviation.

$\underset{\underset{Cl}{\overset{|}{}}}{\overset{Cl}{\overset{\diagdown}{}}}C-H \cdots O=\big\langle$
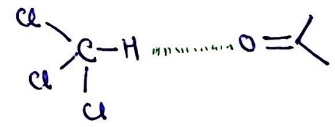
Azeotropes :— Binary mixtures having same composition in liquid and vapour phase and boil at a constant temperature. [$x_A = y_A$ and $x_B = y_B$]
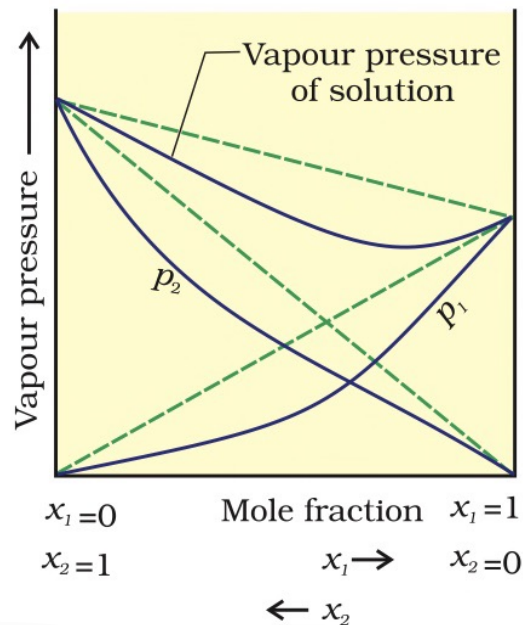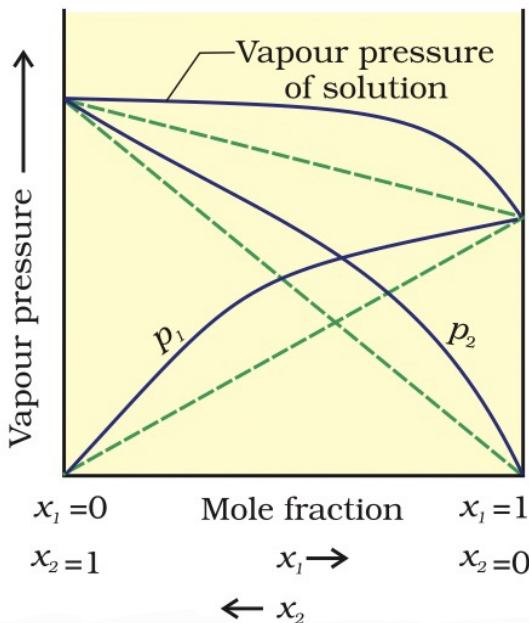
→ Azeotropes can't be seperated into its components by fractional distillations.

→ 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 compositio

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

(ii) **Maximum boiling azeotrope** —: The solution that show large negative deviation from Raoults Law form maximum boiling azeotrope at a specific composition.

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

Colligative Properties

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

→ Colligative Properties α No. of particles in solution $\alpha \dfrac{1}{\text{Molar mass of solute}}$

→ <u>Four Colligative properties</u> —: 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 $p = x_1 p^o$ [$p^o \to$ V.P of pure solvent]

The reduction in the V.P. of solvent $(\Delta p) = p^o - p = p^o - x_1 p^o = (1-x_1)p^o$

$$\Delta p = x_2 p^o \implies \boxed{RLVP \quad \dfrac{\Delta p}{p^o} = x_2}$$

means that, $\underset{\longrightarrow}{RLVP} = \dfrac{\text{mole}}{\text{fraction of}}$ Solute.

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

$$RLVP = \dfrac{p^o - p}{p^o} = x_2 = \dfrac{n_2}{n_2 + n_1}$$

→ For dilute solution $n_2 <<< n_1$ $\Rightarrow$ $\boxed{\dfrac{p^0-p}{p^0} = \dfrac{n_2}{n_1}} = \left(\dfrac{w_2}{M_2}\right)\cdot\left(\dfrac{M_1}{w_1}\right)$

→ 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 308K. Calculate the molar mass of solute. [V.P. of pure water = 32 mm of Hg]

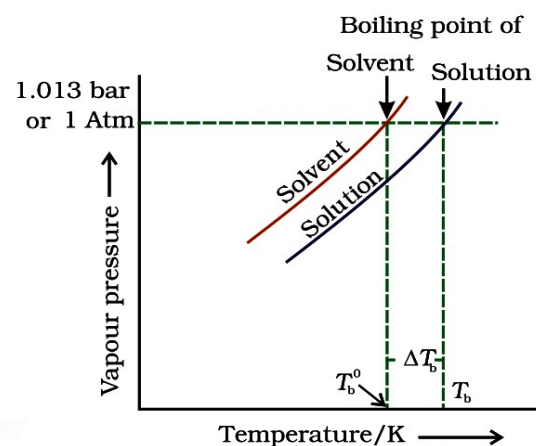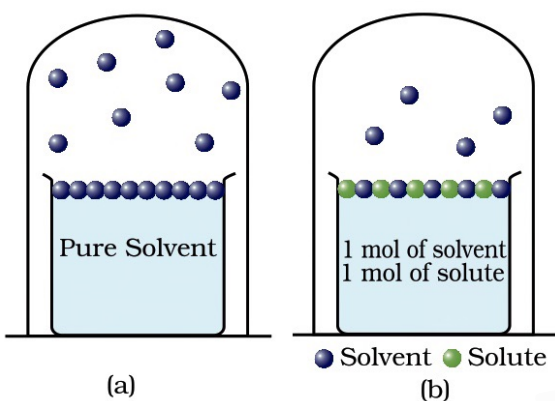**Answer –:** $W_2 = 10\,g$ $W_1 = 200\,g$ $p = 31.04$ mm of Hg

$M_2 = ?$ $M_1 = 18\,g$ $p^0 = 32$ mm of Hg

$\boxed{H_2O}$

Vapour pressure of pure solvent

Vapour pressure ↑

0 Mole fraction of solvent 1
$x_{solvent}$ →
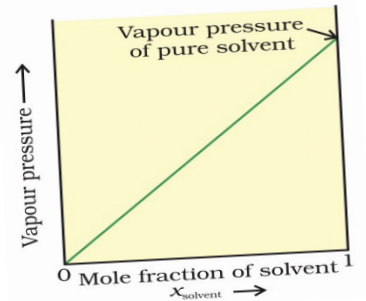
→ $\dfrac{p^0-p}{p^0} = \dfrac{n_2}{n_1} = \dfrac{(W_2/M_2)}{(W_1/M_1)}$ $\Rightarrow$ $\dfrac{32-31.04}{32} = \dfrac{(10/M_2)}{(200/18)}$ then $M_2 = 100\,\dfrac{g}{mol}$

Elevation of boiling point –:

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

Pure Solvent

1 mol of solvent
1 mol of solute

● Solvent ● Solute

(a)   (b)

Boiling point of
Solvent Solution

1.013 bar
or 1 Atm

Vapour pressure ↑

Solvent
Solution

ΔT_b
T_b^0 T_b

Temperature/K →

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

→ for dilute solutions $\Delta T_b \propto m$ [Here m is molality or molal concentration of solute in a solution.]

[CBSE 2012] ① $\boxed{\Delta T_b = k_b \cdot m}$ [k_b : B.P. elevation constant / Molal elevation constant]

→ As unit of $m = \dfrac{mol}{kg}$, so, unit of $k_b = \underline{K \ kg \ mol^{-1}}$.

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

Apni Kaksha :)

Then; $\boxed{\Delta T_b = K_b \cdot \dfrac{1000 \ W_2}{M_2 \cdot W_1}}$ and Molar mass of solute

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

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 K kg mol^{-1}, B.P. of pure water = 373.15 K)   (2M)

[Delhi 2013]

Answer -: $W_1 = 1 kg = 1000 g$ $T_b^° = 373.15$

$W_2 = 10 g$ $K_b = 0.52 \ K \ Kg \ mol^{-1}$ $M_2 = 180 \ g \ mol^{-1}$

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

→ $\Delta T_b = T_b - T_b^° = T_b - 373.15 = 0.052 \ K$

$T_b = 373.15 + 0.052 = 373.202 \ K$

$\underline{T_b = 3.73.2 \ K}$

Question :— A solution of glycerol [$C_3H_8O_3$] in water was prepared by dissolving
some glycerol in 500g of water. This solution has a B.P. of 100.42 °C, What
mass of glycerol was dissolved to make this solution?

K_b for water = 0.512 K kg mol^{-1} (3M) $\begin{bmatrix} CBSE \ 2012 \\ Delhi \ 2012/2010 \end{bmatrix}$

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

$\Delta T_b = T_b - T_b^\circ = 100.42\,°C - 100\,°C = 0.42\,K$

→ $\Delta T_b = k_b \left(\dfrac{W_2}{M_2}\right) \times \left(\dfrac{1000}{W_1}\right) \Rightarrow 0.42 = 0.512 \left(\dfrac{W_2}{92}\right)\left(\dfrac{1000}{500}\right)$

$W_2 = 37.73 g$ = mass of glycerol dissolved.

Apni Kaksha :)

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 that that of pure solvent, as v.p. of solvent decreases in presence of non-volatile solute. [Delhi 2013 c]

→ 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.
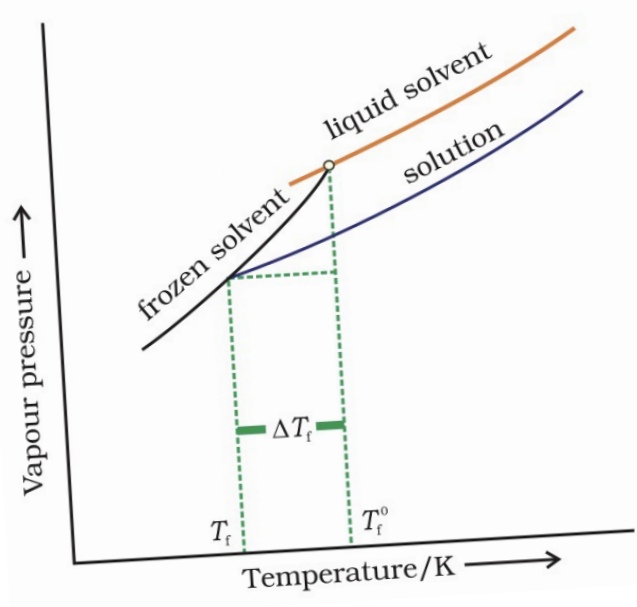
→ $\Delta T_f \propto m$

$\boxed{\Delta T_f = k_f\, m}$

$\underset{.\_.\_.\_.\_.\_.\_.\_.}{\Delta T_f = k_f \times \dfrac{(W_2/M_2)}{(W_1/1000)}}$

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. (Kf of water = 1.06 K kg mol⁻¹)   [Delhi 2010]   (2M)

Answer —: $W_2 = 60 g$ $M_2 = 180 \text{ g mol}^{-1}$ $W_1 = 250 g$

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

$m = 1.33.$

$$\Delta T_f = k_f \cdot m = 1.86 \times 1.33 = 2.47 \, K$$

$$T_f^0 - T_f = 2.47 \, K \qquad [\text{Freezing point of pure water} = 273.15 \, K = 0°C]$$

Freezing point of solution $(T_f) = 273.15 - 2.47$

$$= 270.68 \, K$$

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. ($k_f = 5.12$ K kg mol^{-1}). [CBSE 2014] (2 M)

Answer —: $W_1 = 75 \, g \qquad \Delta T_f = 0.48 \, K \qquad M_2 = 256 \, g \, mol^{-1}$

$$k_f = 5.12 \, K \, kg \, mol^{-1}$$

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

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

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.

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

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

$$\Delta T_f = T_f^0 - T_f = 273.15 - 269.15 = 4 \, K$$

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

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

$$\hookrightarrow \text{then molality } m = \frac{(10/180)}{(90/1000)}$$

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

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

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

Apni Kaksha

<u>Osmosis and Osmotic pressure</u> :- 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 / 2010] (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.
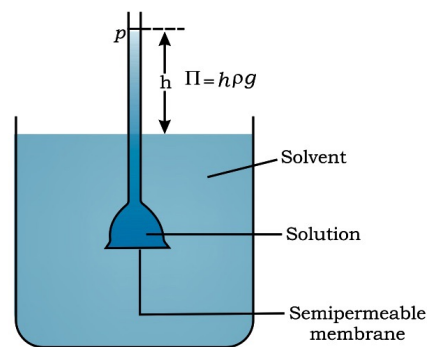
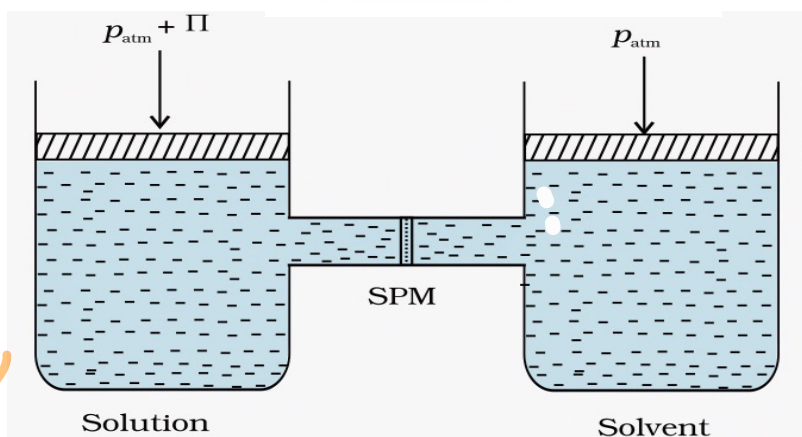→ Osmotic pressure α Molarity (C) (π)

→ $\pi = CRT = \dfrac{n_2}{V} RT$

→ Here, $V \to$ Volume of solution (in L)

$n_2 \to$ Moles of solute $\left(= \dfrac{W_2}{M_2}\right)$

→ $\boxed{\pi = \dfrac{(W_2/M_2)}{V} RT}$

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

<u>Question</u> :- A solution prepared by dissolving 8.95 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] [Delhi 2011] (3M)

<u>Answer</u> -: $W_2 = 8.95$ mg $= 8.95 \times 10^{-3}$ g $V = 35$ ml $= \dfrac{35}{1000}$ L

$\pi = 0.335$ torr $= \dfrac{0.335}{760}$ atm $T = 273 + 25 = 298$ k

→ $\pi = CRT = \dfrac{(W_2/M_2)}{V} RT$ then $M_2 = \dfrac{W_2 RT}{\pi V} = \dfrac{(8.95 \times 10^{-3})(0.082)(298)}{\left(\dfrac{0.335}{760}\right)\left(\dfrac{35}{1000}\right)}$

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

<u>Question</u> :- 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)

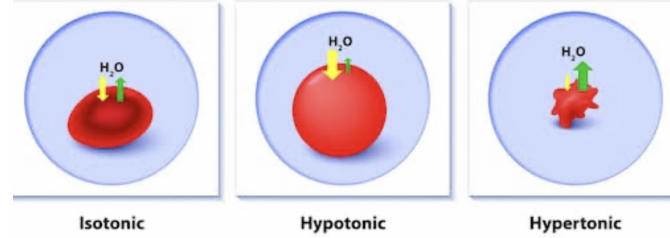$$\rightarrow \quad \pi = CRT = \frac{W_2 RT}{M_2 V}$$

for first solution : $4.98 \text{ bar} = \frac{(36 g) RT}{(100 \text{ g-mol}^{-1}) \cdot V}$ —①

for second solution : $1.52 \text{ bar} = \frac{W_2 RT}{M_2 V}$ —②

Dividing ② by ① :-

$$\frac{1.52}{4.98} = \frac{W_2 RT}{M_2 V} \times \frac{100 V}{36 RT}$$

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

Isotonic   Hypotonic   Hypertonic

Question :- Define the following terms ?

(i) <u>Isotonic Solutions</u> :- 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.

<u>Example</u> → 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 **hypoton** In this case, water will flow into the cells if placed in this solution and they would swell.

Apni Kaksha :)

Hypertonic   Isotonic   Hypotonic

[CBSE 2011 | 2013]

<u>Reverse Osmosis</u> —: 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.
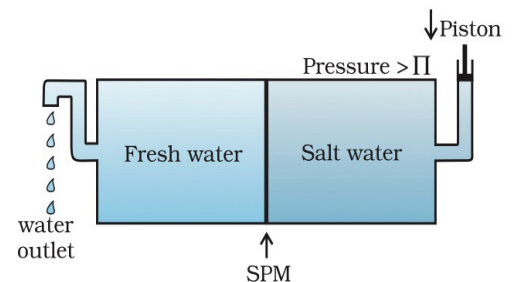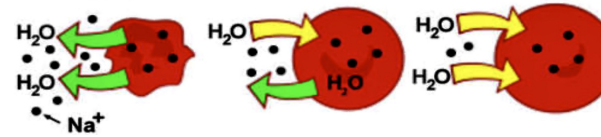
Reverse osmosis occurs when a pressure larger than the osmotic pressure is applied to the solution.

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 2019 | CBSE 2011C | 2010] (2M)

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

1. Pressure measurement is arround 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 (MW = 342 g mol^{-1}) is isotonic with 0.877+ solution of substance x. Find the molecular weight of x. (3M) [CBSE 2015C]

Answer—: $W_{cane\ sugar} = 5g$ $\qquad W_x = 0.877g$

$M_{cane\ sugar} = 342\ g\ mol^{-1}$ $\qquad M_x = ?$

→ Isotonic means same Osmotic pressure
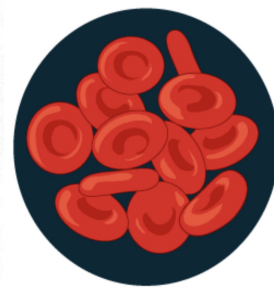
$$\pi_{cane\ sugar} = \pi_x$$
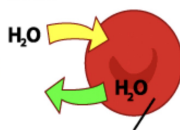
$$\Rightarrow C_{cane\ sugar} \cdot RT = C_x \cdot RT$$

$$\Rightarrow \frac{(W_{cane\ sugar} / M_{cane\ sugar})}{V} = \frac{(W_x / M_x)}{V}$$

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

Isotonic

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

H$_2$O
H$_2$O

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.
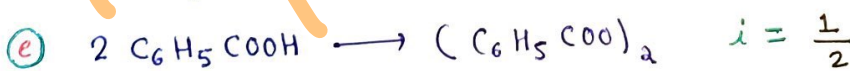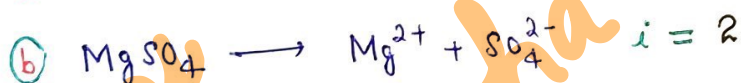
Van't Hoff Factor :-

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 :-

@ $KCl \longrightarrow K^+ + Cl^-$ $i = 2$

ⓑ $MgSO_4 \longrightarrow Mg^{2+} + SO_4^{2-}$ $i = 2$

for Dissociation
$i > 1$

ⓒ $K_2SO_4 \longrightarrow 2K^+ + SO_4^{2-}$ $i = 3$

ⓓ $CaCl_2 \longrightarrow Ca^{+2} + 2Cl^-$ $i = 3$

ⓔ $2 C_6H_5COOH \longrightarrow (C_6H_5COO)_2$ $i = \frac{1}{2}$

for Association
$i < 1$

Dissociation :-

Let the degree of dissociation is α for A_xB_y.

$$A_xB_y \longrightarrow x A^{y+} + y B^{x-}$$

| $t=0$: | C | 0 | 0 |

| t_{eq} : | $C(1-\alpha)$ | $xC\alpha$ | $yC\alpha$ |

Total conc^n at equilibrium

$= C(1-\alpha) + xC\alpha + yC\alpha$

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

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

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

Then; $\boxed{i = 1 + (n-1)\alpha}$

Association :-
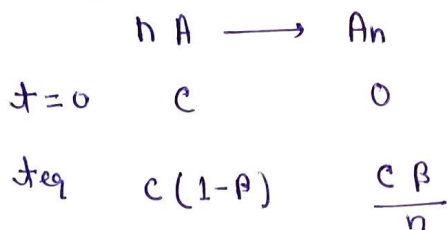
$nA \longrightarrow An$ $\beta \rightarrow$ Degree of association

$t=0$ c 0 For Dimerisation $\boxed{n=2}$

t_{eq} $c(1-\beta)$ $\dfrac{c\beta}{n}$

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

NOTE :- Modification in equations for colligative properties.

(i) RLVP of solvent $\dfrac{P^0 - P}{P^0} = i\,\dfrac{n_2}{n_1}$

(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 $\pi = i\,\dfrac{n_2}{V} RT$

Question :- A 1 molal aq. solution of trichloroacetic acid is heated to its B.P. The solution has B.P. $100.10\,°C$. Determine van't Hoff factor for $CCl_3 COOH$. K_b(water) $= 0.512$ K kg mol^{-1} [Delhi 2012] (2M)

Answer :- $m = 1$, $K_b = 0.512$ K kg mol^{-1} , $T_b = 100.10\,°C$

$\dot{\Delta T_b} = T_b - T_b^° = 100.10 - 100 = 0.10\,°C$ $T_b^°$(water) $= 100\,°C$

$\rightarrow \Delta T_b = i k_b m \Rightarrow 0.10\,K = i \times 0.512 \times 1$ then $i = 0.35$

Question -: calculate the freezing point of an aqueous solution containing $10.5\,g$ of magnesium bromide in $200g$ of water, assuming complete dissociation of $MgBr_2$.

[Molar mass of $MgBr_2 = 184$ g mol^{-1} , k_f (water) $= 1.86$ K kg mol^{-1}] [CBSE 2010C] (3M)

Answer -: $W_2 = 10.50\,g$, $W_1 = 200\,g$, $M_2 (MgBr_2) = 184$ g mol^{-1} , $k_f = 1.86$ K kg mol^{-1}

$MgBr_2 \longrightarrow Mg^{2+} + 2Br^-$: $i = 3$
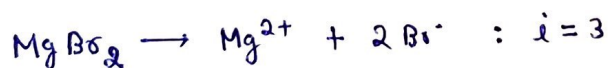
$\rightarrow \Delta T_f = i k_f \cdot m = i k_f \left[\dfrac{W_2 \times 1000}{M_2 \times W_1}\right] = 3 \times 1.86 \left[\dfrac{10.5 \times 1000}{184 \times 200}\right] = 1.592\,K$

$\rightarrow$ freezing point of solution $= T_f^° - \Delta T_f = 273\,K - 1.592\,k = 271.408\,K$

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

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

→ $\Delta T_f = K_f \dfrac{W_2 \times 1000}{M_2 W_1}$

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

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

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

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

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

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

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

Question :– An aq. solution containing 12.48 g of $BaCl_2$ in 1 kg of water at 373.0832 K. Calculate the degree of dissociation of $BaCl_2$.

[Given, $K_b (H_2O) = 0.52 \text{ K kg mol}^{-1}$, molar mass of $BaCl_2 = 208.34 \text{ g mol}^{-1}$] ③M [Delhi 2011C]

Answer –: $W_2 = 12.48 g$, $W_1 = 1000 g$, $T_b \text{(solution)} = 373.0832K$

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

Calculated Molar mass

$\Delta T_b = T_b - T_b^\circ = 373.0832 - 373 = 0.0832 K$

→ $\Delta T_b = K_b \dfrac{W_2 \times 1000}{M_2 \times W_1}$

→ $M_2 = \dfrac{K_b W_2 \times 1000}{\Delta T_b \times W_1} = \dfrac{(0.52)(12.48) \times 1000}{(0.0832) \times 1000} = 78 \text{ g mol}^{-1} = $ Experimental molar mass

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

for $BaCl_2 \longrightarrow Ba^{+2} + 2Cl^-$: $\boxed{i = 1 + (n-1)d}$

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

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