

# SOLUTIONS

by Apni Kaksha ::

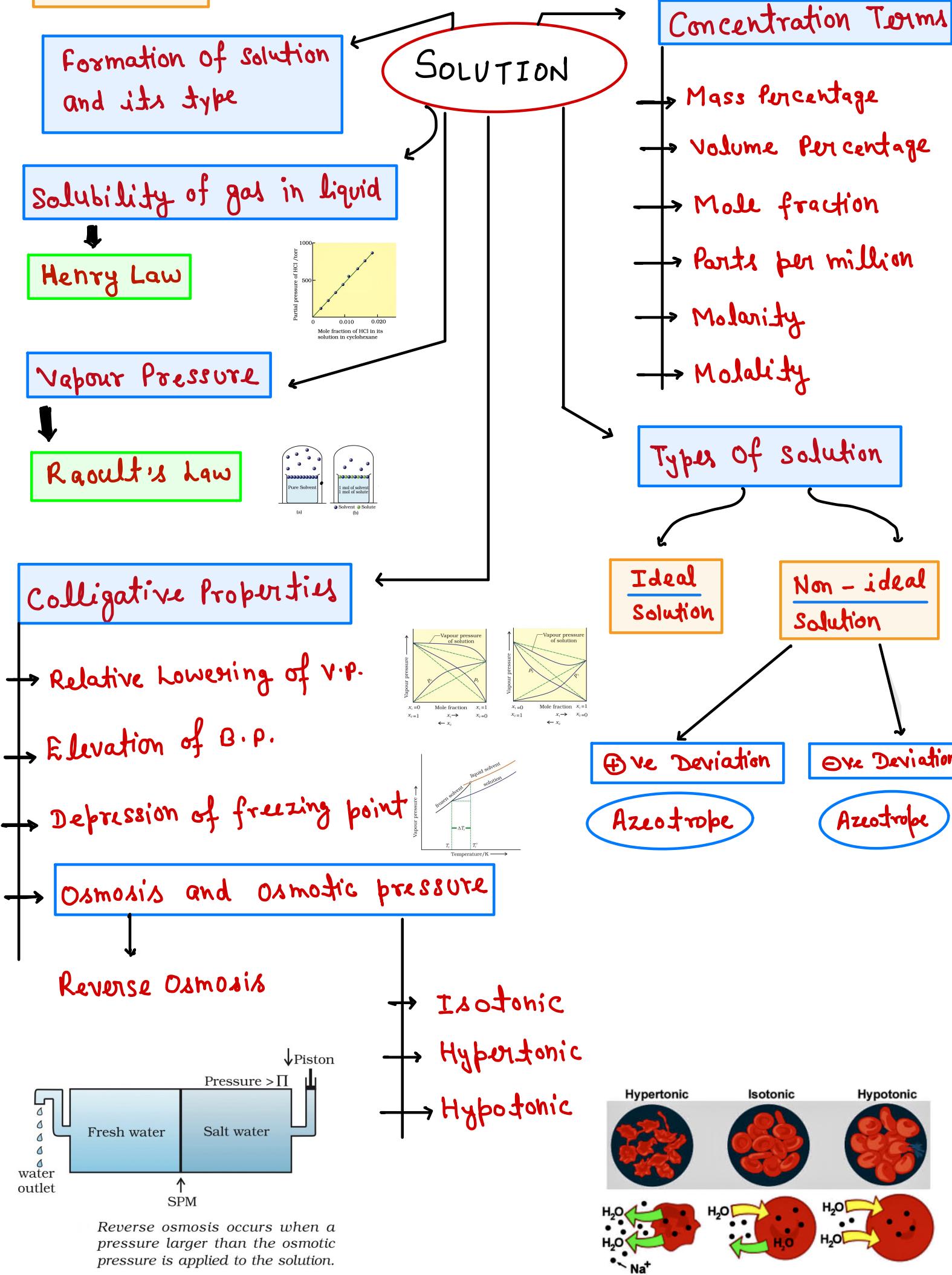
Class XII BOARD EXAMS (Target 100)

These notes have  
been verified by  
CBSE Science Toppers.

Previous 15 year  
Questions have been  
integrated in the  
notes.

Raman  
Dhatarwal

# Flow Chart



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

[CBSE 2015C, 2012, 2010C]  
[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  $x_A = \frac{n_A}{n_A + n_B}$ .

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

→ 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?

$$\rightarrow x_{N_2} = \frac{n_{N_2}}{n_{N_2} + n_{O_2}} = \frac{10}{10+20} = \frac{1}{3} \quad \text{then } x_{O_2} = 1 - \frac{1}{3} = \frac{2}{3}$$

Ans:

## 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 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).

$$\rightarrow \text{Per cent } \frac{w}{v} = \frac{\text{Weight of solute (g)}}{\text{Volume of solution (ml)}} \times 100 \quad \text{similarly; PPM } \left( \frac{w}{v} \right) = \frac{\text{Weight of Solute (g)}}{\text{Volume of soln (ml)}} \times 10^6$$

→ 5.0 PPM O<sub>2</sub> is dissolved in sea :- means 5.0 g of O<sub>2</sub> is dissolved in 10<sup>6</sup> 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.

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

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

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

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

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

(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?

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

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

$$1 \text{ litre} = 1 \text{ dm}^3$$

Solve this after reading concept of molarity

→ A solution of glucose in water is labelled as 10% by weight. What would be the molarity of a solution? [Molar Mass of glucose =  $180 \text{ g mol}^{-1}$ ] [CBSE 2013] 2M

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

$$\text{Then weight of water} = 100 - 10 = 90 \text{ g}$$

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

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

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

\* 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]

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

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

$$\text{Molality } m = \frac{M \times 1000}{1000 \times d - M \times M_2}$$

(No need to memorise this formula)

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

Answer :- 9.8% solution means 9.8 g of  $\text{H}_2\text{SO}_4$  is present in 100 g of the solution.

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

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

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

$$\rightarrow \text{Molarity} = \frac{0.1 \text{ mol}}{0.098 \text{ L}} = 1.02 \text{ mol L}^{-1} = 1.02 \text{ M}$$

Question :- A solution of glucose (Molar mass =  $180 \text{ g mol}^{-1}$ ) 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

$$\text{mass of glucose} = 10\text{ g}$$

$$\text{mass of solution} = 100\text{ g}$$

$$\text{mass of solvent} = 90\text{ g}$$

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

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

# Molar mass of glucose

$$180 \frac{\text{g}}{\text{mol}}$$

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

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

Apni Kaksha



### Solubility

- Solubility of a substance is its maximum amount that can be dissolved in a fix about 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 (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

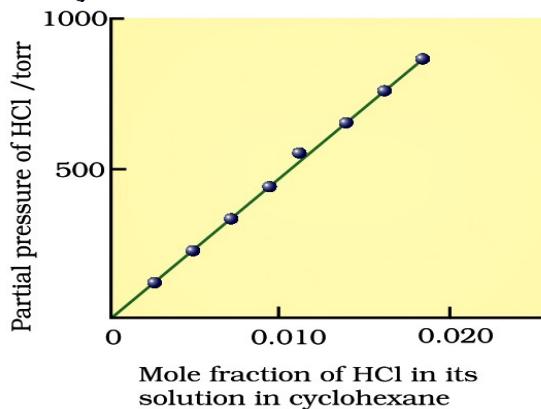
- If we use mole fraction ( $x$ ) of a gas in solution as a measure of its solubility, Then →

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Henry Law Constant :-

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

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 :-

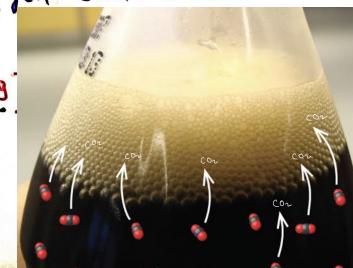
[CBSE 2010] 1M

[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  $6.56 \times 10^{-2}$  g of ethane is 1 bar. If solution contains  $5.0 \times 10^{-2}$  g of ethane, then what will be partial pressure of the gas?

[CBSE 2022C  
Delhi 2011C]

3M

Answer :- According to Henry's Law :-

$$\text{i) mass of ethane & partial pressure } [m_1 = K_H \cdot p_1]$$

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

$$\text{ii) } m_2 = K_H p_2$$

↓

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

Question :- If  $N_2$  gas is bubbled through water at 293 K, how many millimoles of  $N_2$  gas would dissolve in 1L of water? Assume that  $N_2$  exerts a partial pressure of 0.907 bar. given  $\rightarrow K_H = 76.48 \text{ kbar}$  at 293 K. [CBSE 2012C] 3M

Answer :- According to Henry's law :-  $p_{N_2} = K_H \cdot x_{N_2}$

$$x_{N_2} = \frac{p_{N_2}}{K_H} = \frac{0.907 \text{ bar}}{76.48 \times 10^3 \text{ bar}} = 1.29 \times 10^{-5}$$

→ If n moles of  $N_2$  are present in

1L or 1000 g of water then moles of

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

$$\rightarrow \text{Mole fraction of } N_2 = \frac{n}{n + n_{\text{water}}} = \frac{n}{55.5} \quad [n \ll n_{\text{water}}]$$

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

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

### 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 :-  $H_2O(l) \rightleftharpoons H_2O(g)$  Equilibrium constant ( $K_p$ ) =  $\frac{p_{H_2O(g)}}{p_{H_2O(l)}}$

for pure  $H_2O(l)$  :  $p_{H_2O(l)} = 1$  then  $K_p = p_{H_2O(g)}$

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

→ If 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.  $[B.P. \propto \frac{1}{V.P.}]$

### 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 :  $p_2 \propto x_2$

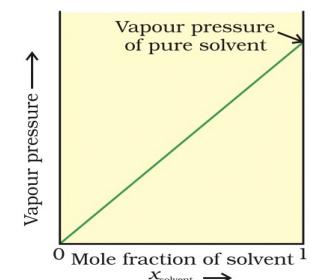
$$p_2 = p_2^0 x_2 \quad \text{(ii)}$$

$p_2^0 \rightarrow$  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.

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

$$[x_1 + x_2 = 1]$$

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

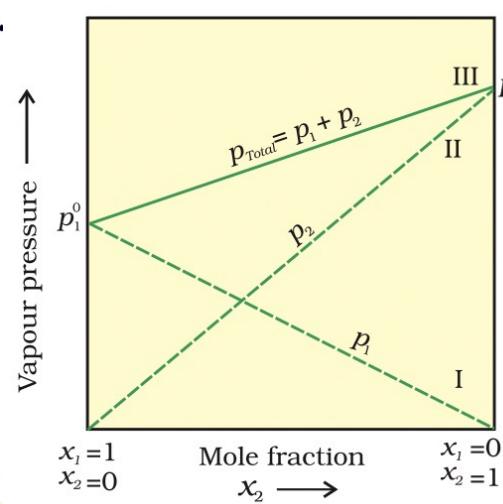
$$\rightarrow y = mx + c$$

→ 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.

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 2013]

Answer:-  $p_A^\circ = 450 \text{ mm of Hg}$   $p_B^\circ = 700 \text{ mm of Hg}$  3 M  
 $p_T = 600 \text{ mm of Hg}$   $x_A / x_B / y_A / y_B ?$

$$\rightarrow p_T = p_A^\circ + (p_A^\circ - p_B^\circ) x_A \Rightarrow 600 = 700 + (450 - 700) x_A$$

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

mole fraction of B in liquid phase  $x_B = 1 - x_A = 1 - 0.40 = 0.60$

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

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

$$p_A = y_A p_T \Rightarrow y_A = \text{mole fraction of A in vapour phase} = \frac{p_A}{p_T} = \frac{180}{600} = 0.30$$

$$p_B = y_B p_T \Rightarrow y_B = \frac{p_B}{p_T} = \frac{420}{600} = 0.70$$

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  $\Rightarrow$  is directly proportional to mole fraction :  $p = k_H \cdot x$  — (ii)  
 then its solubility Henry's law ↑

→ When  $K_H$  becomes equal to  $P^\circ$  [ 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  
 [CBSE 2012 / 2013 / 2014]

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

$$P_A = x_A P_A^\circ$$

$$P_B = x_B P_B^\circ$$

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.  $\Delta H_{mix} = 0$

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

Example → h-Hexane and n-Heptane

bromobethane 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.

$$P_A \neq x_A P_A^\circ$$

$$P_B \neq x_B P_B^\circ$$

iii) Component A + component B → Component AB

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

Apni Kaksha :

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  $CH_3COOH$

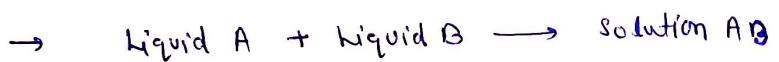
$CH_4$  and  $Cl_4$ .

→ 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.

[Delhi 2015]

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

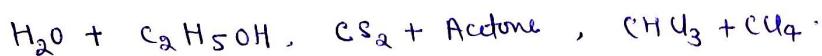


$$\Delta H_{\text{mix}} = +\text{ve}$$

2M

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

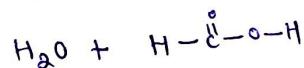
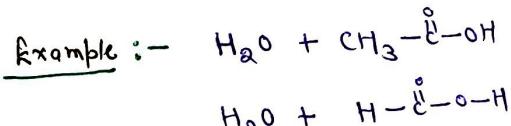
Example—:  $\text{H}_2\text{O} + \text{CH}_3\text{OH}$ , Ethanol + Acetone



(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.

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

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



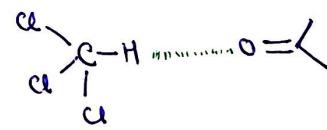
phenol + Aniline



[Delhi 2011c]

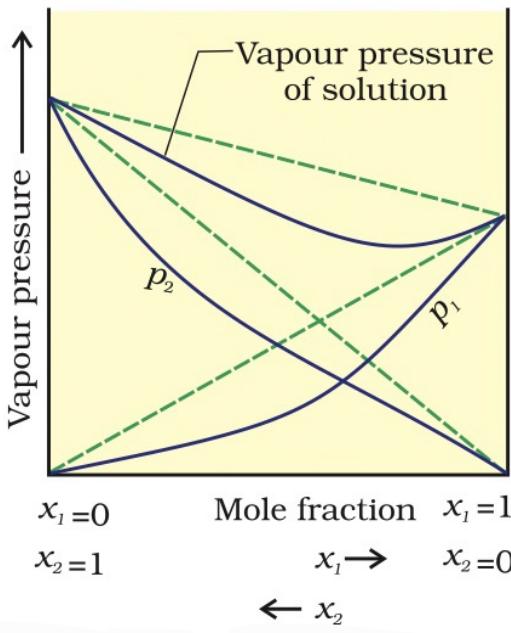
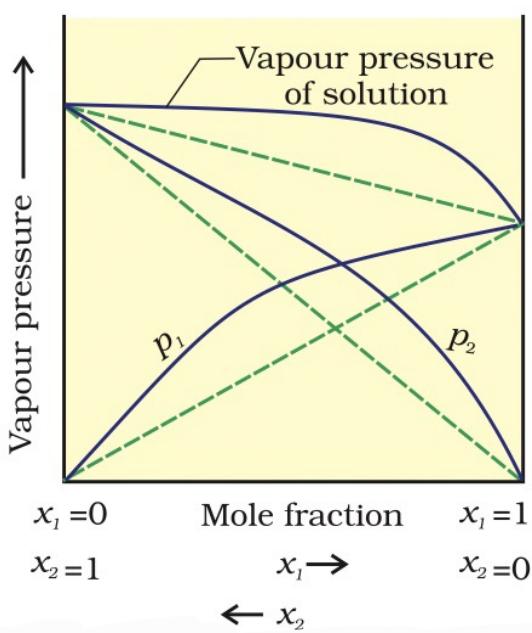
[CBSE 2010/2011]  
[Delhi 2010]

→ A solution of  $\text{CH}_4$  [Chloroform] and  $\text{CH}_3-\ddot{\text{O}}-\text{CH}_3$  (Acetone) shows eve deviation? Why?  
In pure  $\text{CH}_4$  and pure acetone, there is no hydrogen bonding but after mixing there is hydrogen bonding between hydrogen of  $\text{CH}_4$  and oxygen of acetone. Due to strong interaction between solution molecules, vapour pressure decreases which results in eve deviation.



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

[CBSE 2013]  
[Delhi 2014/15] 1M



- Azeotropes can be separated into its components by fractional distillation.
- 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.
- For example :-  $HNO_3 + H_2O$  [68% nitric acid + 32% water by mass]

**Apni Kaksha :-**

1M  
[Delhi 2017]

### Colligative Properties

- 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 ]

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

$$\Delta p = x_2 p^{\circ} \Rightarrow \boxed{\text{RLVP} \quad \frac{\Delta p}{p^{\circ}} = x_2}$$

means that,  $\text{RLVP} = \frac{\text{mole fraction of Solute}}{\text{Solute}}$

- If  $n_1$  and  $n_2$  are numbers 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  $n_2 \ll n_1 \Rightarrow \frac{p^o - p}{p^o} = \frac{n_2}{n_1} = \left(\frac{w_2}{M_2}\right) \cdot \left(\frac{M_1}{W_1}\right)$

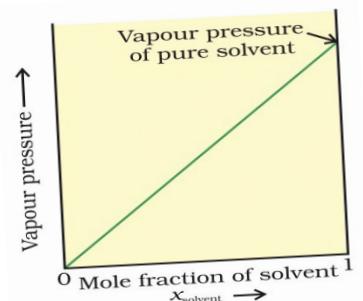
→ Here  $w_1$  and  $w_2$  are the masses and  $M_1$  and  $M_2$  are the molar masses of solvent and solute respectively.

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 300K. Calculate the molar mass of solute. [v.p. of pure water = 32 mm of Hg] [CBSE 2015] 3M

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

$$M_2 = ? \quad M_1 = 10 \text{ g} \quad p^o = 32 \text{ mm of Hg}$$

$\text{H}_2\text{O}$



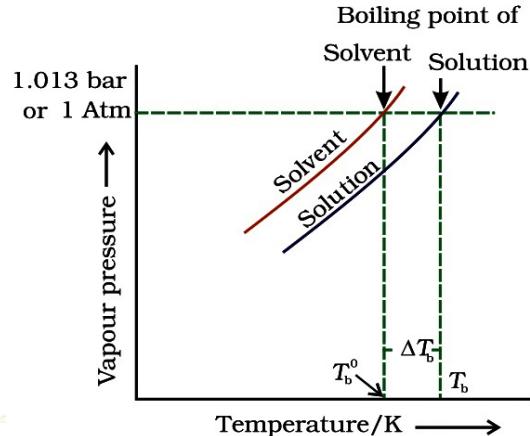
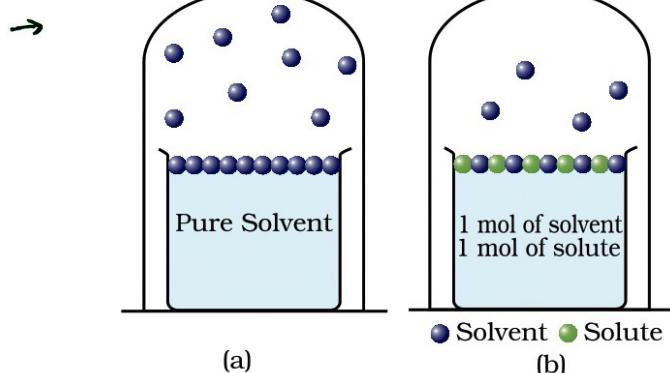
$$\rightarrow \frac{p^o - p}{p^o} = \frac{n_2}{n_1} = \frac{(w_2/M_2)}{(w_1/M_1)} \Rightarrow \frac{32 - 31.04}{32} = \frac{(10/M_2)}{(200/10)} \text{ then } M_2 = 100 \text{ g/mol}$$

### Elevation of boiling point :-

→ As we know B.P. of a liquid is a temperature at which its v.p. becomes equal to the 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 molecule gets reduced. So the no. of solvent molecules escaping from surface is reduced. Thus the v.p. is also reduced. [Delhi 2014c] 2M



→ If  $T_b^\circ$  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]

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

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

[ $K_b$  : B.P. elevation constant / Molal elevation constant]

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

If  $w_2$  g of solute of molar mass  $M_2$  is dissolved in  $w_1$  g of solvent, then

$$\text{molality of solution } m = \frac{(w_2/M_2) \text{ mole}}{(w_1/1000) \text{ kg}}$$

Then;

$$\Delta T_b = K_b \cdot \frac{1000 w_2}{M_2 \cdot w_1}$$

and Molar mass of solute

$$M_2 = \frac{1000 w_2 \cdot K_b}{\Delta T_b \cdot w_1}$$

**Aloni Kaksha :-**

Questions :- 10 g of glucose (molar mass = 180 g mol<sup>-1</sup>) 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<sup>-1</sup>, B.P. of pure water = 373.15 K)

[Delhi 2013]

2M

Answer :-  $w_1 = 1 \text{ kg} = 1000 \text{ g}$        $T_b^\circ = 373.15$

$$w_2 = 10 \text{ g} \quad K_b = 0.52 \text{ K kg mol}^{-1} \quad M_2 = 180 \text{ g mol}^{-1}$$

$$\Delta T_b = K_b \cdot m = K_b \cdot \frac{1000 w_2}{M_2 \cdot w_1} = 0.52 \times \frac{1000 \times 10}{180 \times 1000} = 0.052 \text{ K}$$

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

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

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

Question :- A solution of glycerol [C<sub>3</sub>H<sub>8</sub>O<sub>3</sub>] 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?

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

3M

[CBSE 2012]

[Delhi 2012/2010]

Answer →  $M_2 = 92 \text{ g mol}^{-1}$      $w_1 = 500 \text{ g}$      $w_2 = ?$      $K_b = 0.512 \text{ K kg mol}^{-1}$

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

$$\rightarrow \Delta T_b = K_b \left( \frac{w_2}{M_2} \right) \times \left( \frac{1000}{w_1} \right) \Rightarrow 0.42 = 0.512 \left( \frac{w_2}{92} \right) \left( \frac{1000}{500} \right)$$

$w_2 = 37.73 \text{ g}$  = 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 than 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.

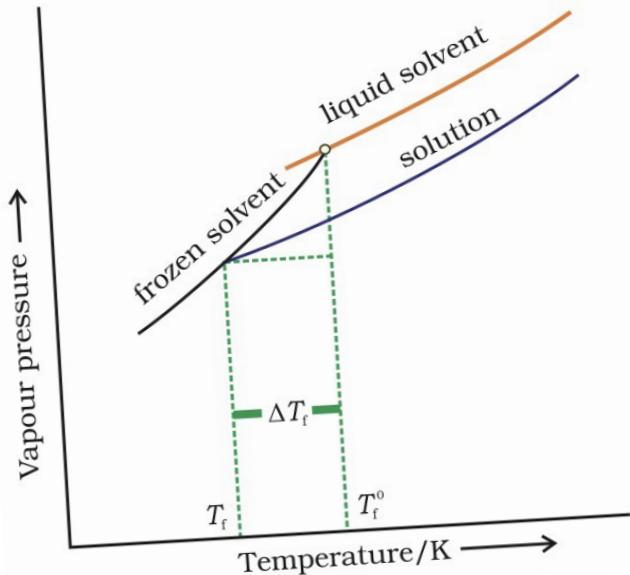
$$\Delta T_f = T_f^{\circ} - T_f$$

Freezing point of pure solvent      ↓  
 Freezing point of solution.

→  $\Delta T_f \propto m$

$$\boxed{\Delta T_f = K_f m}$$

$$\boxed{\Delta T_f = K_f \times \frac{(w_2/M_2)}{(w_1/1000)}}$$



$K_f$  → Freezing Point Depression constant.  
 $m$  → Molal Depression constant.  
 $c$  → cryoscopic constant.

Question :- Calculate the freezing point of a solution containing 60 g of glucose (molar mass =  $180 \text{ g mol}^{-1}$ ) in 250 g of water. ( $K_f$  of water =  $1.06 \text{ K kg mol}^{-1}$ )

[Delhi 2018]

Answer :-  $w_2 = 60 \text{ g}$      $M_2 = 180 \text{ g mol}^{-1}$      $w_1 = 250 \text{ g}$

2M

$$\text{molality of solution} \Rightarrow m = \left( \frac{w_2}{M_2} \right) \times \frac{1000}{w_1} \Rightarrow \frac{60 \text{ g}}{180 \text{ g mol}^{-1}} \times \frac{1000}{250 \text{ g mol}^{-1}}$$

$$m = 1.33$$

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

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

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

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

[CBSE 2014] 2M

$$\text{Answer} : \quad w_1 = 75 \text{ g} \quad \Delta T_f = 0.48 \text{ K} \quad M_2 = 256 \text{ g mol}^{-1}$$

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

$$\rightarrow \Delta T_f = k_f \cdot m = \frac{k_f \cdot w_2 \cdot 1000}{w_1 \cdot M_2} \Rightarrow 0.48 = \frac{5.12 \times w_2 \times 1000}{75 \times 256}$$

$$w_2 = \text{mass of solute} = 1.0 \text{ g}$$

Question :— A 10% solution (by mass) of sucrose in water has freezing point of  $269.15 \text{ K}$ . Calculate freezing point of 10% glucose in water. If freezing point of pure water is  $273.15 \text{ K}$ .

[Delhi 2017] 3M

[Given : molar mass of sucrose =  $342 \text{ g mol}^{-1}$ ; Molar mass of glucose =  $180 \text{ g mol}^{-1}$ ]

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

$$\rightarrow w_2 = 10 \text{ g} \quad w_1 = 90 \text{ g} \quad M_2 = 342 \text{ g mol}^{-1}$$

$$\text{then molality } m = \frac{(w_2/M_2)}{(w_1/1000)} = \frac{(10/342)}{(90/1000)} = 0.324 \text{ mol kg}^{-1}$$

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

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

$$\# \text{ For glucose solution : } w_2 = 10 \text{ g} \quad w_1 = 90 \text{ g} \quad M_2 = 180 \text{ g mol}^{-1}$$

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

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

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

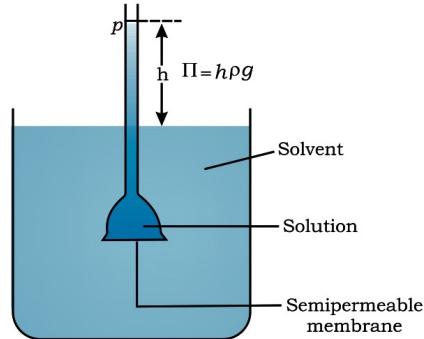
$$m = 0.617 \frac{\text{mol}}{\text{kg}}$$

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

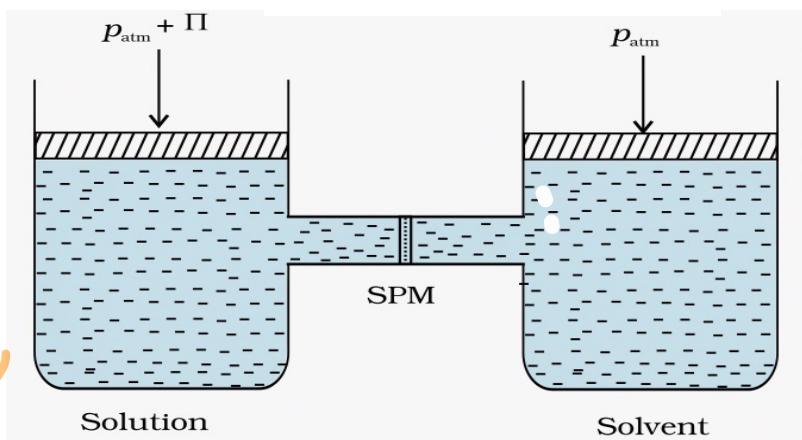
- The hydrostatic pressure which develops on account of osmosis is called Osmotic pressure.
- The pressure which just stops the flow of solvent is called Osmotic pressure of solution.
- Osmotic pressure & Molarity (C)



$$\rightarrow \Pi = C RT = \frac{n_2}{V} RT$$

Here,  $V \rightarrow$  volume of solution (in L)  
 $n_2 \rightarrow$  Moles of solute ( $= \frac{w_2}{M_2}$ )

$$\rightarrow \Pi = \frac{(w_2/M_2)}{V} RT$$



→  $M_2 = \frac{w_2 RT}{\Pi V}$  → Osmotic pressure is used to determine molar masses of macromolecules like protein, 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]  
[Delhi 2011]

Answer :-  $w_2 = 0.95 \text{ mg} = 0.95 \times 10^{-3} \text{ g}$        $V = 35 \text{ ml} = \frac{35}{1000} \text{ L}$

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

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

$$\rightarrow \Pi = C RT = \frac{(w_2/M_2)}{V} RT \quad \text{then} \quad M_2 = \frac{w_2 RT}{\Pi V} = \frac{(0.95 \times 10^{-3})(0.002)(298)}{\left(\frac{0.335}{760}\right)\left(\frac{35}{1000}\right)}$$

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

Question :- At 300K, 36 g of glucose (molar mass = 180 g/mol) 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

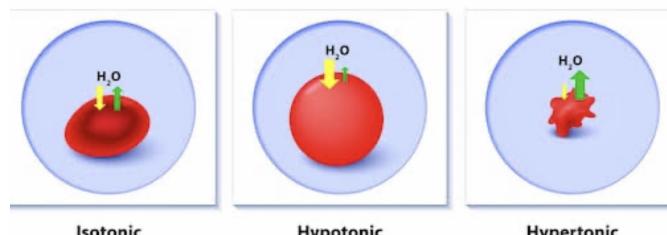
$$\rightarrow \pi = CRT = \frac{w_2 RT}{M_2 V} \quad \text{for first solution : } 4.98 \text{ bar} = \frac{(368) KT}{(180 \text{ g/mol}) \cdot V} \quad \text{--- (1)}$$

$$\text{for second solution : } 1.52 \text{ bar} = \frac{w_2 RT}{M_2 V} \quad \text{--- (2)}$$

Dividing (2) by (1) :-

$$\frac{1.52}{4.98} = \frac{w_2 RT}{M_2 V} \times \frac{180V}{36 RT}$$

$$\frac{w_2}{M_2} = 0.061 \text{ mol}$$



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.

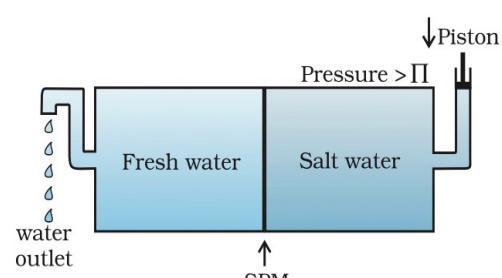
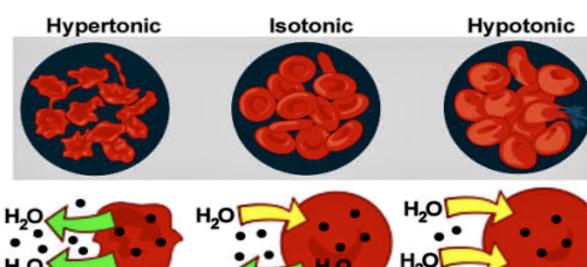
→ If the salt concentration is less than 0.9% (m/v), the solution is said to be hypotonic. In this case, water will flow into the cells if placed in this solution and they would swell.

Apni Kaksha ☺

[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 PY Q'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  $\text{NaCl}$ . 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  $\text{NaCl}$  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. [CBSE 2015C] 3M

Answer-:  $w_{\text{cane sugar}} = 5 \text{ g}$        $w_x = 0.877 \text{ g}$   
 $M_{\text{cane sugar}} = 342 \text{ g mol}^{-1}$        $M_x = ?$

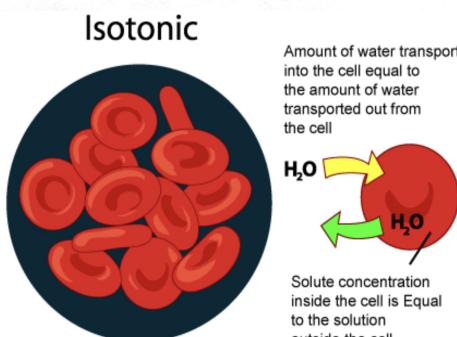
→ Isotonic means  
same osmotic pressure

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

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

$$\Rightarrow \frac{(w_{\text{cane sugar}} / M_{\text{cane sugar}})}{V} = \frac{(w_x / M_x)}{V}$$

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



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. [Delhi 2016] 1M