Solutions and Colligative properties

In this Session :
- Weightage of concepts
- Revision of Entire chapter
- Revising important formula
- Solving previous year questions

Weightage of Concepts

Concentration terms (Molarity, Molality, Normality, ppm) - 15-20%
Vapor pressure and Raoult's law (including deviations) - 15-18%
Solution thermodynamics (ΔH, ΔG of mixing) - 12-15%
Colligative properties - 20-25%

Definition

- A solution is a homogeneous mixture of two or more substances
- Components:
  - Solute: Substance present in lesser amount
  - Solvent: Substance present in larger amount

Types of Solutions

1. Based on physical state (solute/solvent):
   - Gas in Gas (e.g., Air - O_2 in N_2)
   - Gas in Liquid (e.g., O_2 in H_2O)
   - Gas in Solid (e.g., H_2 in Pd)
   - Liquid in Liquid (e.g., Ethanol in water)
   - Liquid in Solid (e.g., Hg in Ag amalgam)
   - Solid in Liquid (e.g., NaCl in water)

- Solid in Solid (e.g., Cu in Au)

2. Solubility

Definition

Maximum amount of solute that can be dissolved in a given amount of solvent at a specific temperature

Factors Affecting Solubility

A. For Solids in Liquids

1. Temperature Effect:
   - Endothermic dissolution ($\Delta solH > 0$): Solubility increases with temperature
   - Exothermic dissolution ($\Delta solH < 0$): Solubility decreases with temperature
2. Pressure Effect:
   - Negligible effect on solids and liquids ✓
   - Like dissolves like principle applies (polar-polar, nonpolar-nonpolar)

B. For Gases in Liquids

1. Henry's Law:
   - $p = KH \times x$ $p \propto x$ K_H
   - where:
     - p = partial pressure of gas
     - x = mole fraction of gas in solution
     - KH = Henry's constant
   - Higher KH means lower solubility
2. Temperature Effect:
   - Generally decreases with increasing temperature (exothermic process)

3. Raoult's Law and Solutions

"Like dissolves Like"

"non-polar Polar"

Ideal Solutions

1. Characteristics:
   - Obey Raoult's Law at all conditions
   - $p_1 = x_1 p_1^\circ$; $p_2 = x_2 p_2^\circ$
   - $\Delta Hmix = 0$, $\Delta Vmix = 0$
   - A-B interactions ≈ A-A and B-B interactions

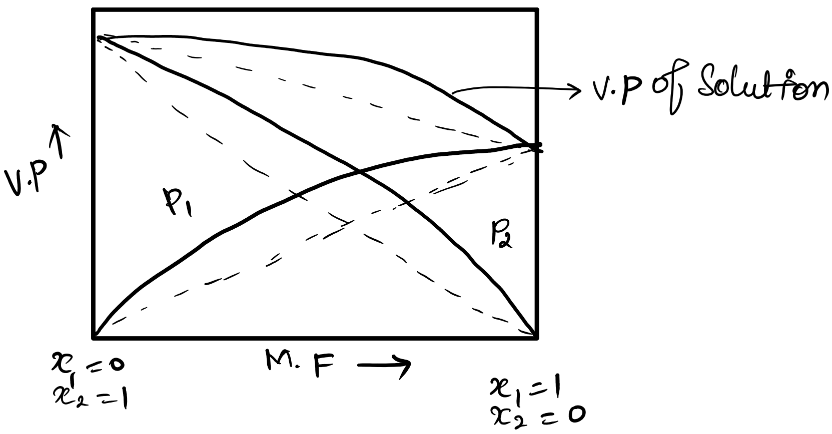
A—B ≈ B—B

- $\Delta H_{mix} = 0$, $\Delta V_{mix} = 0$
- A-B interactions ≈ A-A and B-B interactions
- No azeotropes formation

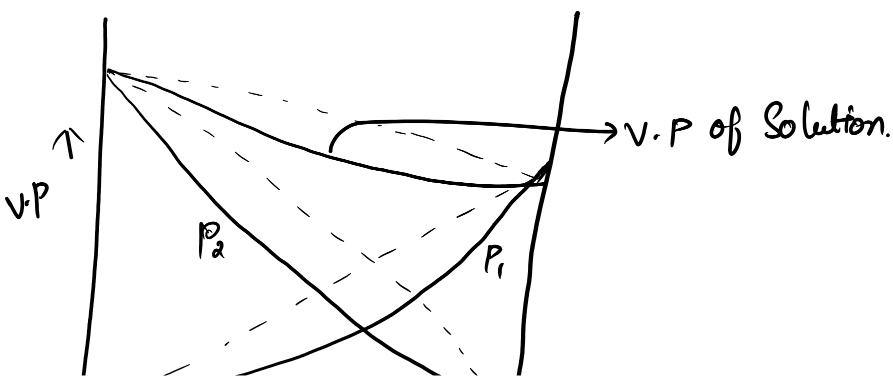
A-B ≈ A-A = B-B

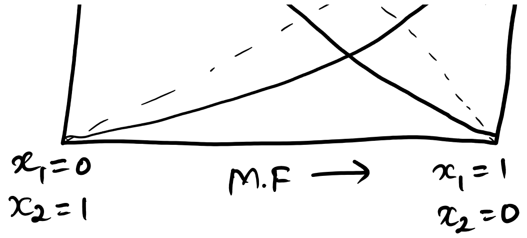
Non-ideal Solutions

1. Positive Deviation:
   - A-B < A-A or B-B interactions
   - $\Delta H_{mix} > 0$, $\Delta V_{mix} > 0$
   - $p_i > p_i^\circ . x_i$
   - Forms minimum boiling azeotropes
   - Examples: Ethanol-water, acetone-methanol



1. Negative Deviation:
   - A-B > A-A or B-B interactions
   - $\Delta H_{mix} < 0$, $\Delta V_{mix} < 0$
   - $p_1 < p_1^\circ x_1$
   - Forms maximum boiling azeotropes
   - Examples: HCl-water, chloroform-acetone





4. Colligative Properties

A. Relative Lowering of Vapor Pressure

n - no. of moles.

- $(p^\circ_1 - p_1)/p^\circ_1 = n_2/(n_1 + n_2)$
- For dilute solutions: $= x_0$ (mole fraction of solute)

B. Elevation in Boiling Point

- $\Delta T_b = K_b \times m$
- K_b = boiling point elevation constant
- m = molality

C. Depression in Freezing Point

- $\Delta T_f = K_f \times m$
- K_f = freezing point depression constant (Cryoscopic Constant)
- m = molality

D. Osmotic Pressure

C - Conc. $\Rightarrow \frac{\text{no. of moles}}{\text{Vol.}}$

- $\pi = CRT$
- $\pi = nRT/V$
- For dilute solutions: $\pi = MRT$

Van't Hoff Factor (i)

- i = Observed colligative property/Calculated colligative property
- For association: $i < 1$
- For dissociation: $i > 1$
- Relation with degree of dissociation (α):
  - For dissociation: $i = 1 + (n-1)\alpha$ $\alpha = \frac{i-1}{n-1}$
  - For association: $i = 1 - (1-1/n)\alpha$ $\alpha = \frac{1-i}{1-\frac{1}{n}}$

Modified Equations

For electrolytes with van't Hoff factor:

- $\Delta T_b = iK_b \times m$
- $\Delta T_f = iK_f \times m$

- $\pi = iMRT$

Question 1 (JEE Advanced 2023)

Q. A solution containing 6.0 g of a non-electrolyte solute in 200 g of water has an osmotic pressure of 2.46 atm at 27°C (R = 0.082 L·atm/K·mol). The molar mass of the solute is:

$$\pi = MRT$$

$$\text{Molarity} = \frac{\text{moles}}{\text{Volume}} = \frac{\frac{6}{MM}}{0.2\,L}$$

$$27 + 273 = 300$$

$$2.46 = \frac{6}{MM \times 0.2} \times 0.082 \times 300$$

$$MM = \frac{6 \times 0.082 \times 300}{2.46 \times 0.2} = 180\ g/mol.$$

Question 2 (JEE Main 2022)

Q. Two liquids A and B form an ideal solution. At 298 K, the vapor pressure of pure A is 450 mm Hg and that of pure B is 700 mm Hg. Calculate the vapor pressure of solution containing 3 moles of A and 7 moles of B.

$$P_T = P_A^0 x_A + P_B^0 x_B$$

$$x_A = \frac{3}{10} \qquad x_B = \frac{7}{10}$$

$$= 450 \times \frac{3}{10} + 700 \times \frac{7}{10}$$

$$\boxed{P_T = 625\ mm\ Hg.}$$

Question 3 (JEE Advanced 2021)

Q. 100 g of ice at 0°C is added to 100 g of water at 50°C in a closed insulated vessel. The final temperature and state of the system will be: (Latent heat of fusion of ice = 80 cal/g)

Let final temp $T^{\circ}C$

Heat lost by hot water = 100 ×

Q. A solution of glucose ($C_6H_{12}O_6$) in water is in equilibrium with water vapor at 298 K. If the vapor pressure of pure water at 298 K is 23.8 torr and vapor pressure of solution is 22.4 torr, calculate the molality of the solution.

$$\frac{p^0 - p}{p^0} = X_{solute} = X_{glucose}$$

$X_{water} =$

$n_{water} = \frac{1000}{18} = 55.5$ mol

$$\Rightarrow \frac{23.8 - 22.4}{23.8} = 0.0588$$

$$\Rightarrow X_{glucose} = \frac{n_{glucose}}{n_{water} + n_{glucose}} = 0.0588 = \frac{n_{glu}}{55.5 + n_{glu}}$$

$n_{glucose} = 3.48$ moles.

molality = 3.48 m

Question 5 (JEE Main)

Q. The Henry's law constant for the solubility of methane in water at 298 K is 4.1×10^5 atm. The mole fraction of methane in water at 1 atm pressure will be:

$K_H = 4.1 \times 10^5$ atm.

$P = k_H x$

$K_H = 4.1 \times 10$ atm.

$P = K_H \, x_{methane}$.

$1 = 4.1 \times 10^5 \, x_{methane}$.

$x_{methane} = \frac{1}{4.1 \times 10^5} = 2.44 \times 10^{-6}$

(JEE 2018)

The Henry's law constant for the solubility of N2 gas in water at 298 K is 1.0 X 10^5 atm. The mole fraction of N2 in air is 0.8. The number of moles of N2 from air dissolved in 10 moles of water at 298 K and 5 atm pressure is

(a) 4.0 x 10^-4

(c) 5.0X 10^4

(b) 4.0X10^-5

(d) 4.0 X 10^-6

K_H

$x_{N_2} = 0.8$

$n_{H_2O} = 10$ moles

$p = 5$ atm

$p_{N_2} = P_T \, x_{N_2}$

$= 5 \times 0.8 = 4$

$x_{N_2} = \frac{n_{N_2}}{n_{N_2} + n_{H_2O}}$

$p_{N_2} = K_H \, x_{N_2}$

$4 = 1 \times 10^5$

$x_{N_2} = 4 \times 10^{-5}$

$4 \times 10^{-5} = \frac{n_{N_2}}{n_{N_2} + 10}$

$n_{N_2} = 4 \times 10^{-4}$

$\times \, n_{N_2} + 10 \Rightarrow 4 \times 10^{-5} (n_{N_2} + 10) = n_{N_2}$

$4 \times 10^{-5} n_{N_2} + 4 \times 10^{-4} = n_{N_2}$

$4 \times 10^{-4} = 0.99 \, n_{N_2}$

$n_{N_2} = 4 \times 10^{-4}$

A solution containing 4 g of polyvinyl chloride polymer in one litre of dioxane was found to have an osmotic pressure of 4.1 x 10^-4 atm. at 27°C. The approximate molecular weight of the polymer is

(a) 1500	(c) 2.4x 10^5

(b) 10,000 (d) 2X 10^12

$\pi = 4.1 \times 10^{-4}$

mass = 4 g

$T = 27^\circ C = 300 K$

$\pi = MRT$

$4.1 \times 10^{-4} = \frac{4}{MM \times 1} \times 0.082 \times 300$

$MM = \frac{4 \times 0.082 \times 300}{4.1 \times 10^{-4}} = 2.4 \times 10^5$

When 20 g of naphthoic acid (C11H8O2) is dissolved in 50 g of benzene (Krf= 1.72 K kg mol-1), a freezing point depression of 2 K is observed. The van't Hoff factor (i) is

(a) 0.5

(c) 2

(b) 1

(d) 3

$\Delta T_f = i \times K_f \times m$

$2 = i \times 1.72 \times \frac{20}{172} \times \frac{1000}{50}$

$i = \frac{2 \times 172 \times 50}{1.72 \times 20 \times 1000} = 0.5$

11 x 12
8 x 1
2 x 16
172

Phenol dimerises in benzene having van't Hoff factor 0.54. What is the degree of association?

(a) 0.46
(c) 46
(b) 92
(d) 0.92

$i = 0.54$

$\alpha = 1 - i \times \left(\frac{n}{n-1}\right)$

$= 1 - 0.54 \times \frac{2}{2-1}$

$= 0.46 \times 2 = 0.92$

Which of the following solution would exhibit abnormal colligative properties?

(a) 0.1 M sucrose ✗
(b) 1 M glucose ✗
(c) 10 g glass powder in water ✗
(d) 0.1 M NaCl