Solutions and Colligative Properties

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:

Solution:

1. Given:
    - Mass of solute = 6.0 g
    - Mass of water = 200 g
    - π = 2.46 atm
    - T = 27°C + 273 = 300 K
    - R = 0.082 L·atm/K·mol
2. Using osmotic pressure equation: π = MRT where M = molarity = (moles of solute)/(volume in L)
3. Volume of solution ≈ 0.2 L (assuming density ≈ 1 g/mL) 2.46 = (6.0/molar mass × 1/0.2) × 0.082 × 300
4. Solving for molar mass: Molar mass = 180 g/mol

Answer: 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.

Solution:

1. For ideal solutions, Raoult's law applies: Ptotal = PA° × xA + PB° × xB
2. Calculate mole fractions:
    - Total moles = 10
    - xA = 3/10 = 0.3
    - xB = 7/10 = 0.7
3. Apply Raoult's law: Ptotal = 450 × 0.3 + 700 × 0.7 = 135 + 490 = 625 mm Hg

Answer: 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)

Solution:

1. Let final temperature be T°C Heat lost by hot water = 100 × 1 × (50 - T) Heat gained by ice = 100 × 80 + 100 × 1 × T
2. At equilibrium: 100(50 - T) = 8000 + 100T 5000 - 100T = 8000 + 100T 5000 = 8000 + 200T -3000 = 200T T = -15°C
3. Since final temperature is below 0°C, all water will freeze.

Answer: -15°C, all water frozen

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.

Solution:

1. Using Raoult's law for vapor pressure lowering:
    - $(p° - p)/p° = x(solute)$
    - $(23.8 - 22.4)/23.8 = x(glucose)$
    - $0.0588 = x(glucose)$
2. For dilute solutions:
    - $x(solute) = n(solute)/(n(solute) + n(solvent))$
    - $0.0588 = n(glucose)/(n(glucose) + n(water))$
    - $n(water) = 1000/18 = 55.56$ moles (per kg)
3. Solve for n(glucose):
    - $0.0588 = n/(n + 55.56)$
    - $n = 3.48$ moles
4. Therefore, molality = 3.48 mol/kg

Answer: 3.48 molal

Question 5 (JEE Main 2019)

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

Solution:

1. Using Henry's law:
    - $p = KH \times x$
    - $1 = 4.1 \times 10^5 \times x$
    - $x = 2.44 \times 10^{-6}$ (mole fraction)
2. Convert to molarity:
    - Moles of water in 1L = 55.56 mol
    - Moles of methane = $55.56 \times 2.44 \times 10^{-6}$
    - Molarity = 1.35×10^{-4} M

Answer: 1.35×10^{-4} M

Question 6 (JEE Advanced 2018)

Q. For an aqueous solution of two volatile liquids A and B forming a minimum boiling azeotrope with xA = 0.4, the total vapor pressure is 180 mm Hg. If the vapor pressure of pure A is 200 mm Hg and that of pure B is 250 mm Hg at the same temperature, calculate the mole fraction of A in vapor phase.

Solution:

1. For azeotropic mixture:
    - yA = xA (composition same in both phases)
    - Total pressure = 180 mm Hg
    - xA = 0.4
2. Using Dalton's law:
    - P(total) × yA = pA
    - 180 × yA = 200 × 0.4
    - yA = 0.4
3. Verify positive deviation:
    - Calculated P(total) using Raoult's law = 230 mm Hg
    - Actual P(total) = 180 mm Hg
    - Shows positive deviation

Answer: 0.4

Question 7 (JEE Main 2017)

Q. A 0.1 molal solution of K_2SO_4 is 92% dissociated. Calculate the van't Hoff factor for the solution.

Solution:

1. Dissociation equation: $K_2SO_4 \rightarrow 2K^+ + SO_4^{2-}$
2. For 92% dissociation: α = 0.92
3. Calculate particles produced:
    - Each molecule produces 3 ions
    - Number of moles of undissociated = 0.08
    - Number of moles of ions = 0.92 × 3 = 2.76
4. Van't Hoff factor: i = (2.76 + 0.08)/1 = 2.84

Answer: 2.84

Q. A mixture of chloroform and acetone shows positive deviation from Raoult's law. When 1 mol of chloroform is mixed with 2 mol of acetone, the vapor pressure of chloroform at 298 K is found to be 275 mm Hg. Calculate the vapor pressure of pure chloroform if its mole fraction in vapor phase is 0.424.

Solution:

1. Given:
    - n($CHCl_3$) = 1 mol
    - n(acetone) = 2 mol

- $P(CHCl_3)$ = 275 mm Hg
- $y(CHCl_3)$ = 0.424

2. Calculate mole fraction in liquid phase:
   - $x(CHCl_3)$ = 1/(1+2) = 0.333
3. Using modified Raoult's law:
   - $y(CHCl_3)P = x(CHCl_3)\gamma(CHCl_3)P°(CHCl_3)$
   - $0.424 \times (275/0.333) = P°(CHCl_3)$
4. Calculate: $P°(CHCl_3)$ = 220 mm Hg

Answer: 220 mm Hg

Question 9 (JEE Main 2015)

Q. A solution of glycerol ($C_3H_8O_3$) in water was prepared by dissolving 4.0 g of glycerol in 50 g of water. Calculate the freezing point of the solution. (Kf for water = 1.86 K·kg/mol, freezing point of pure water = 273.15 K)

Solution:

1. Calculate molality:
   - Molar mass of glycerol = 92 g/mol
   - Moles of glycerol = 4.0/92 = 0.0435 mol
   - Mass of water = 50 g = 0.050 kg
   - Molality = 0.0435/0.050 = 0.87 m
2. Calculate ΔTf:
   - $\Delta Tf = Kf \times m$
   - $\Delta Tf = 1.86 \times 0.87$
   - $\Delta Tf = 1.62$ K
3. Calculate freezing point:
   - Tf = 273.15 - 1.62
   - Tf = 271.53 K

Answer: 271.53 K or -1.62°C

Question 10 (JEE Advanced 2014)

Q. At 300 K, the vapor pressure of a solution containing a non-volatile solute in water is 31.67 mm Hg. Calculate the molal concentration of the solution if the vapor pressure of pure water at this temperature is 32.8 mm Hg.

Solution:

1. Using Raoult's law:
   - $P = P° \times x_{solvent}$
   - $31.67 = 32.8 \times x_{water}$
2. Calculate xwater:
   - xwater = 31.67/32.8 = 0.966
   - xsolute = 1 - 0.966 = 0.034
3. For dilute solutions:

- xsolute = $n_2/(n_1 + n_2)$
- $0.034 = n_2/(55.56 + n_2)$
- n_2 = 1.95 moles per kg of water

Answer: 1.95 molal

Question 11 (JEE Main 2013)

Q. The osmotic pressure of a 0.0100 M aqueous solution of NaCl at 27°C is closest to: (R = 0.0821 L · atm/K · mol) [Given: NaCl is 85% dissociated]

Solution:

1. Calculate van't Hoff factor:
   - $NaCl \rightarrow Na^+ + Cl^-$
   - $\alpha = 0.85$
   - $i = 1 + \alpha(n-1) = 1 + 0.85(2-1) = 1.85$
2. Calculate osmotic pressure:
   - $\pi = iMRT$
   - $\pi = 1.85 \times 0.0100 \times 0.0821 \times 300$
   - $\pi = 0.456$ atm

Answer: 0.456 atm