Solutions and Colligative Properties

1. Concentration Terms

A. Molarity (M)

- M = Number of moles of solute/Volume of solution in liters
- M = (Mass of solute × 1000)/(Molecular mass of solute × Volume in mL)
- Temperature dependent
- $M_1V_1 = M_2V_2$ (Dilution formula)

B. Molality (m)

- m = Number of moles of solute/Mass of solvent in kg
- m = (Mass of solute × 1000)/(Molecular mass of solute × Mass of solvent in g)
- Temperature independent

C. Normality (N)

- N = (Molarity × Basicity/Acidity)
- N = Number of gram equivalents/Volume in liters
- For acid-base mixtures:
  - If $V_1N_1 = V_2N_2$: solution is neutral
  - If $V_1N_1 > V_2N_2$: solution is acidic
  - If $V_1N_1 < V_2N_2$: solution is basic
- Normality of acidic mixture = $(V_1N_1 - V_2N_2)/(V_1 + V_2)$
- Normality of basic mixture = $(V_2N_2 - V_1N_1)/(V_1 + V_2)$

D. Mole Fraction (x)

- $x_1 = n_1/(n_1 + n_2)$
- For dilute solutions: $x_2 = mM_1/(1000 + mM_1)$
- Sum of all mole fractions = 1

E. Mass Percentage

- Mass % = (Mass of solute/Mass of solution) × 100

F. Volume Percentage

- Volume % = (Volume of solute/Volume of solution) × 100

G. Parts Per Million (ppm)

- ppm = (Mass of solute/Mass of solution) × 10^6

2. Ionic Strength

- $I = \frac{1}{2}\Sigma c_i z_i^2$
  - where c_i = molarity of ion
  - z_i = charge on ion
- For 1:1 electrolyte, I = concentration
- For multivalent ions, I > concentration

3. Vapor Pressure & Raoult's Law

A. Raoult's Law for Volatile Components

- $p(\text{total}) = p_1 + p_2 = x_1p_1^\circ + x_2p_2^\circ$
- For ideal solutions: $p_1 = x_1p_1^\circ$
- Mole fraction in vapor phase: $y_1 = p_1/(p_1 + p_2)$

B. Raoult's Law for Non-volatile Solutes (Dilute Solutions)

- $(p^\circ - p_1)/p^\circ = n_2/(n_1 + n_2) = x_2$
- Relative lowering = $(p^\circ - p)/p^\circ = x_2$ (for dilute solutions)

4. Colligative Properties & van't Hoff Factor Modifications

A. Relative Lowering of Vapor Pressure

- For non-electrolytes: $(p^\circ - p)/p^\circ = x(\text{solute}) = n_2/(n_1 + n_2)$
- For electrolytes: $(p^\circ - p)/p^\circ = i \times x(\text{solute})$ where i = van't Hoff factor

B. Elevation in Boiling Point

- For non-electrolytes: $\Delta T(b) = K(b) \times m$
- For electrolytes: $\Delta T(b) = i \times K(b) \times m$
- For partial dissociation: $i = [1 + \alpha(n-1)]$
  - $\Delta T(b) = K(b) \times m \times [1 + \alpha(n-1)]$ Example: For NaCl (complete dissociation): $\Delta T(b) = 2 \times K(b) \times m$ For $CaCl_2$ (complete dissociation): $\Delta T(b) = 3 \times K(b) \times m$

C. Depression in Freezing Point

- For non-electrolytes: $\Delta T(f) = K(f) \times m$
- For electrolytes: $\Delta T(f) = i \times K(f) \times m$
- For partial dissociation: $\Delta T(f) = K(f) \times m \times [1 + \alpha(n-1)]$ Example: For $Al_2(SO_4)_3$ (complete dissociation): $\Delta T(f) = 5 \times K(f) \times m$

D. Osmotic Pressure (π)

- For non-electrolytes: $\pi = CRT = MRT$
- For electrolytes: $\pi = iMRT$
- For partial dissociation: $\pi = MRT[1 + \alpha(n-1)]$ Example: For weak acid HA (α = degree of dissociation): $\pi = MRT[1 + \alpha]$

E. van't Hoff Factor (i) Calculations

1. For Complete Dissociation:
   - $NaCl \rightarrow Na^+ + Cl^-$ (i = 2)
   - $CaCl_2 \rightarrow Ca^{2+} + 2Cl^-$ (i = 3)
   - $Al_2(SO_4)_3 \rightarrow 2Al^{3+} + 3SO_4^{2-}$ (i = 5)
2. For Partial Dissociation:
   - $i = 1 + \alpha(n-1)$ where: α = degree of dissociation n = number of ions formed after dissociation
3. For Association:
   - $i = 1 - \alpha$ where: α = degree of association
4. Special Cases:
   - For acids: $i = 1 + \alpha$
   - For bases: $i = 1 + \alpha$
   - For association of x molecules to form 1 molecule: $i = [1 + (1-\alpha)(1/x - 1)]$

F. Abnormal Molar Mass Calculations

1. Using vapor pressure: $M_2 = (W_2 \times R_1 \times 1000)/(W_1 \times \text{Relative lowering} \times i)$
2. Using boiling point elevation: $M_2 = (W_2 \times 1000 \times K(b))/(W_1 \times \Delta T(b) \times i)$
3. Using freezing point depression: $M_2 = (W_2 \times 1000 \times K(f))/(W_1 \times \Delta T(f) \times i)$
4. Using osmotic pressure: $M_2 = (W_2 \times 1000)/(W_1 \times i)$

6. Mixing Solutions

- For same solute:
  - $M_1V_1 + M_2V_2 = M(V_1 + V_2)$
  - $N_1V_1 + N_2V_2 = N(V_1 + V_2)$

7. Special Terms

- Isotonic solutions: Same osmotic pressure at same temperature
- Hypotonic solution: Lower osmotic pressure
- Hypertonic solution: Higher osmotic pressure
- Isosmotic solutions: Same osmotic pressure
- Reverse osmosis: When pressure > osmotic pressure

8. For Chemical Reactions

- $M_1/V_1 \propto M_2/V_2$
  - where n_1 and n_2 are stoichiometric coefficients

9. Non-ideal Solutions

- Positive deviation: p(total) > Raoult's law prediction
- Negative deviation: p(total) < Raoult's law prediction
- Azeotropes: Constant boiling mixtures