Chemistry 103

Chapter 13

Physical
Properties of Solutions

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Physical Properties of Solutions

Solution: Uniform dispersal of one substance or more throughout another (Homogeneous mixture).

1. **Solute:** the minor component in solution.

2. **Solvent:** the major component in solution.

Types of Solutions:

1. **Saturated Solution:** Contains the maximum amount of solute that will dissolve in a given amount of solvent.
2. **Unsaturated Solution:** the solvent contains less solute than it has capacity to dissolve.
3. **Supersaturated Solution:** the solvent contains more solute than it has the capacity to dissolve.

Solvation: the interaction between the solute and solvent molecules.

Hydration: the interaction between the solute and solvent molecules when the solvent is water.

Concentration Units:
1. Mass Percent:

$$mass\,\%\;of\;\;A = \frac{mass\;of\;\;A}{mass\;of\;\;Solution} \times 100$$

%A + %B + %C + …. = 100

2. Part Per Million (ppM):

$$ppm\;of\;\;A = \frac{mass\;of\;\;A}{mass\;of\;\;Solution} \times 10^6$$

Used for dilute solutions.

3. Par per Billion (ppb):

$$ppb\;of\;\;A = \frac{mass\;of\;\;A}{mass\;of\;\;Solution} \times 10^9$$

Used for ultradilute solutions.

4. Mole fraction (X):

$$mole\ fraction\ of\ A = \frac{moles\ of\ A}{Total\ moles\ of\ all\ components}$$

or

$$X_A = \frac{n_A}{n_A + n_B + n_c + ...}$$

$X_A + X_B + X_C + ... = 1$

5. Molarity (M):

$$molarity = \frac{moles\ of\ solute}{Liters\ of\ solution}$$

or

$$M = \frac{n}{V(L)}$$

6. Molality (m):

$$molality = \frac{moles\ of\ solute}{ki\log rams\ of\ solvent}$$

or

$$m = \frac{n}{kg's}$$

Example: A solution is made by mixing 4.35 g glucose (M = 180.2 g/mol) in 25 g of water. The density of the solution is 1.05 g/mL. Calculate the concentration of glucose in:

1. mass percent:

$$mass\,\%\ of\ \ A = \frac{mass\ of\ \ A}{mass\ of\ \ Solution} \times 100$$

$$\%glu\cos e = \frac{4.35}{(4.35 + 25)} \times 100$$

=15%

2. mole fraction.

$$X_{glucose} = \frac{n_{glucose}}{n_{glucose} + n_{H2O}}$$

$$n_{glucose} = \frac{4.35\ g}{180.2\ g/mol} = 0.024$$

$$n_{H2O} = \frac{25}{18} = 1.39$$

$$X_{glucose} = \frac{0.024}{0.024 + 1.39} = 0.017$$

3. in molarity:

$$molality = \frac{moles\ of\ \ solute}{Liters\ of\ \ solution}$$

$$moles\ of\ \ glu\cos e = 0.024$$

$$volume\, of\ \ solution = massofsolution \times \frac{1}{density}$$

$$volume\, of\ \ solution = (4.35 + 25) \times \frac{1}{1.05} = 27.9\ mL$$

$$molarity = \frac{0.024}{0.0279} = 0.86\ M$$

4. In molality.

$$molality = \frac{moles\ of\ \ solute}{ki\log rams\ of\ \ solvent}$$

$$moles\ of\ \ glu\cos e = 0.024$$

$$ki\log rams\, of\ \ solvebt = 25\ g = 0.025\ kg$$

$$m = \frac{0.024}{0.025} = 0.096\ m$$

Example: A 100 g sample of mineral water was found to contain 2.5 mg of sodium. Calculate the concentration of sodim in

A. ppm

$$ppm\ of\ \ A = \frac{mass\ of\ \ A}{mass\ of\ \ Solution} \times 10^6$$

$$ppm\ of\ \ Na = \frac{2.5 \times 10^{-3}}{100} \times 10^6 = 25\ \ ppm$$

B. ppb.

$$ppb\ of\ \ A = \frac{mass\ of\ \ A}{mass\ of\ \ Solution} \times 10^9$$

$$ppb\ of\ \ Na = \frac{2.5 \times 10^{-3}}{100} \times 10^9 = 25 \times 10^3\ \ ppb$$

Example: An aqueous solution of HCl contains 36% HCl by mass and has density of 1.1 g /mL. Calculate the concentration of this solution:

A. mole fraction.

B. in molality.

C. In molarity.

100 g of solution contains 36 g of HCl and 64 g of H_2O

A.

$$X_{HCl} = \frac{n_{HCL}}{n_{HCl} + n_{H2O}}$$

$$n_{HCl} = \frac{36.}{36.5} = 0.98\ mol$$

$$n_{H2O} = \frac{64}{18} = 3.6\ mol$$

$$X_{HCl} = \frac{0.98}{0.98 + 3.6} = 0.21$$

B.

$$\mathrm{m_{HCl}} = \frac{\text{mol HCl}}{\text{kg's of H2O}}$$

$$\mathrm{m_{HCl}} = \frac{0.98}{64\text{x}10^{-3}} = 15.3\ m$$

C.

$$M = \frac{\text{Mol HCl}}{\text{Liters of solution}}$$

$$\text{Liters of solution} = 100\text{g} \times \frac{1\text{mL}}{1.1\text{g}} \times \frac{1L}{1000mL} = 0.091L$$

$$M = \frac{0.98}{0.091} = 10.76\ M$$

Example: The concentration of an aqueous solution of glucose $C_6H_{12}O_6$ (M=180g/mol) is 0.5 mol/L and its density is 1.05 g/mL. Calculate the molal concentration of this solution.

1 L of solution contains 0.5 mol (90 g) of glucose.

The mass of 1 L of solution is = 1000 mL x 1.05 g/mL
= 1050 g

1050 g of a solution contain 0.5 mol (90 g) of glucose and 960 g of H_2O.

$$\text{m}_{\text{glucose}} = \frac{\text{mol glucose}}{\text{kg's of } H_2O}$$

$$\text{m}_{\text{HCl}} = \frac{0.5}{960\text{x}10^{-3}} = 0.52\ m$$

Example: the molality of a solution of glucose in water is 1 mol/kg and its density is 1.07 g/mL. Calculate the molarity of glucose in this solution.

1 mol glucose =180 g

1180 g solution contains 1 mol (180 g) glucose and 1000 g H_2O.

$$\text{Liters of the sol.} = 1180\,\text{g} \times \frac{\text{mL}}{1.07\,\text{g}} \times \frac{1\,L}{1000\,mL} = 1.1\,L$$

$$M = \frac{\text{mol glucose}}{\text{Liters of solution}}$$

$$M = \frac{1\,mol}{1.1\,L} = 0.91\,mol/L$$

Colligative Properties of Nonelectrolytic Solutions:

Colligative Properties: Properties of solution that depends on concentration but not on the type of solute.

Colligative Properties are:

1. Vapor pressure lowering.
2. Freezing point depression.
3. Boiling point elevation.
4. Osmotic pressure.

1.Vapor Pressure Lowering:

Volatile substance: has a vapor pressure.
Nonvolatile substance: has no vapor pressure.

Raoults Law

$$P_A = X_A P_A{}^o$$

P_A the vapor pressure of A in solution
X_A mole fraction of A
$P_A{}^o$ the vapor pressure of pure A.

Ideal Solution: Solutions that obey Raoult's Law.

Example: Glycerin (M = 92.1 g/mol) is a non volatile substance with density of 1.26 g/mL at 25 ^oC. A solution is made by mixing 50 mL of glycerin with 50 mL of water. If the vapor pressure of pure water at 25 ^oC is 23.8 torr, calculate the vapor pressure of this solution.

$$P_{H2O} = X_{H2O} P^o{}_{H2O}$$

$$mol\ glycerine = 50\ mL \times 1.26 \frac{g}{mL} \times \frac{1\,mol}{92.1\ g} = 0.684$$

$$mol\ H_2O = 50\ mL \times 1.00 \frac{g}{mL} \times \frac{1\,mol}{18\ g} = 2.78$$

$$X_{H2O} = \frac{2.78}{2.78 + 0.68} = 0.80$$

$$P_{H2O} = 0.80 \times 23.8\ torr = 19.1\ torr$$

2. Boiling Point Elevation:

$$\Delta T_b = K_b m$$

ΔT_b is the elevation in Boiling point.

K_b: the molal boiling point elevation constant. It depends only on the solvent.

m molality of solution.

3. **Freezing point Depression:**

$$\Delta T_f = K_f m$$

ΔT_f is the depression in freezing point.

K_f: the molal freezing point depression constant. It depends only on the solvent.

m molality of solution.

Example: Automotive antifreeze consist of ethylene glycol $C_2H_6O_2$ (M= 62.1 g/mol) and water. Calculate the boiling point and the freezing point of a solution that is 25% ethylene glycol in water. K_f and K_b for water are 1.86 $^oC/m$ and 0.51 $^oC/m$, respectively.

100 g of solution contain 25 glycol and 75 g water.

Calculation of freezing point

$$m_{gly} = \frac{\text{mol glycol}}{\text{kg's of } H_2O}$$

$$mol\ gly = \frac{25}{62.1} = 0.40$$

$$m_{gly} = \frac{0.4}{0.075} = 5.3\ mol/kg$$

$$\Delta T_f = K_f m$$

$$\Delta T_f = 1.86 \times 5.3 = 9.92\ ^oC$$

$$T_f = 0 - 9.92 = -9.92\ ^oC$$

Calculation of boiling point

$$\Delta T_b = K_b m$$

$$\Delta T_b = 0.51 \times 5.3 = 2.7\ ^oC$$

$$T_f = 100 + 2.70 = 102.7\ ^oC$$

Example: List the following aqueous solution in order increasing freezing point and boiling point.

1) 0.15 m NaCl
2) 0.1 m HCl
3) 0.05 m glucose ($C_6H_{12}O_6$)
4) 0.05 m acetic acid (CH_3COOH).
5) 0.05 $CaCl_2$

Solution	Molality of salt	Molality of ions
NaCl	0.15	0.30
HCl	0.10	0.20
$C_6H_{12}O_6$	0.05	0.05
CH_3COOH	0.05	$0.05 < m < 0.1$
$CaCl_2$	0.05	0.15

Freezing point:
NaCl < HCl < $CaCl_2$ < CH_3COOH < $C_6H_{12}O_6$

Boiling point:

$C_6H_{12}O_6$ < CH_3COOH < $CaCl_2$ < HCl < NaCl

Osmosis

Osmosis: the movement of solvent from dilute to concentrated solution.

Semipermeable membrane: membranes that are permeable to some molecules but not others.

Osmotic Pressure (π): the pressure that must be exerted to stop the movement of solvent.

$$\pi \propto MT$$

$$\pi = MRT$$

$$M = \frac{n}{V}$$

$$\pi = \left(\frac{n}{V}\right)RT$$

$$\pi V = nRT$$

Isotonic Solutions: solutions that have equal osmotic pressure.

Hypotonic: a solution having lower osmotic pressure.

Hypertonic: a solution having higher osmotic pressure.

Example: What is the osmotic pressure at 20 ^{o}C of a 0.002 M sucrose solution?

$$\pi = MRT$$

$$\pi = 0.002\ \frac{mol}{L} \times 0.0821\ \frac{L\ atm}{K\ mol} \times 293\ K = 0.048\ atm$$

Example: The osmotic pressure of blood is 7.7 atm. What is the concentration of glucose solution that is isotonic with blood at 37 ^{o}C?

Determination of Molar Mass

Example: A solution is made by dissolving 0.25 g of unknown substance in 40 g CCl_4 (K_b = 5.02 $^oC/m$). The boiling point of the solution was 0.357 ^oC higher than the boiling point of the pure solvent. Calculate the molar mass of the unknown substance.

$$\Delta T_b = K_b m$$

$$m = \frac{\Delta T_b}{K_b}$$

$$m = \frac{0.357}{5.02} = 0.0711\, m$$

$$m = \frac{mol\ of\ \ solute}{kg's\ of\ \ solvent}$$

$$mol\ of\ \ solute = 0.0711\, \frac{mol}{kg} \times 0.04\ kg = 2.84 \times 10^{-3}$$

$$mol = \frac{m}{M}$$

$$M\ = \frac{0.25}{2.84 \times 10^{-3}} = 88.0\ g / mol$$

Example: The osmotic pressure of a solution made by dissolving 3.5 mg of a protein in enough water to form 5 mL solution is 1.54 torr at 25 ^{o}C. Calculate the molar mass of the protein.

$$\pi = MRT$$

$$M = \frac{\pi}{RT}$$

$$1\ atm = 760\ torr$$

$$M = \frac{1.54\ torr \times \dfrac{1\ atm}{760\ torr}}{0.0821\ L\ atm\ /\ K\ mol \times 298\ K} = 8.28 \times 10^{-5}\ mol/L$$

$$mol\ of\ \ protein = M \times V(L)$$

$$mol\ of\ \ protein = 8.28 \times 10^{-5} \times 5 \times 10^{-3} = 4.14 \times 10^{-7}$$

$$M = \frac{m}{n}$$

$$M = \frac{3.5 \times 10^{-3}\ g}{4.14 \times 10^{-7}\ mol} = 8.45 \times 10^{3}\ g/mol$$