

SOLUTIONS

- **Solution:** A solution is a homogeneous mixture of two or more substances.
- **Solvent:** It is that component of a solution that has the same physical state as the solution itself.
- **Solute:** It is the substance that is dissolved in a solvent to form a solution.
- **The Concentration of a Solution:** Some of the properties of solutions, e.g. the sweetness of a sugar solution or the color of a dye solution, depend on the amount of solute compared to that of the solvent in it.
 - This is called the solution concentration.
- **Molarity:** Molarity is defined as the number of moles of solute dissolved per litre of solution and is usually denoted by M .
- **Molality:** It is defined as the number of moles of solute dissolved per kilogram of solvent.
- **Normality:** Normality is another concentration unit. It is defined as the number of gram equivalent weights of solute dissolved per litre of the solution.
- **Equivalent weight:** The number of parts by weight of a substance (element or compound) that will combine with or displace, directly or indirectly 1.008 parts by weight of hydrogen, 8 parts by weight of oxygen and 35.5 parts by weight of chlorine is known as equivalent weight.
- **Mole Fraction:** The mole fraction of a component in a solution is the ratio of its number of moles to the total number of moles of all the components in the solution.
- **Mass Percentage:** Mass percentage is the mass of solute present in 100 g of solution.
- **Types of solutions:**
 - (1) **Depending upon the dissolution of the solute in the solvent:**
 - (a) supersaturated solution, (b) unsaturated solution and (c) saturated solution
 - (2) **Depending on whether the solvent is water or not:** (a) Aqueous solution, (b) Non-aqueous solution
 - (3) **Depends on the amount of solute added to the solvent:**
 - (a) Dilute solution and (b) Concentrated solution
 - (4) **Based on appearances:**
 - (a) Homogenous and (b) Heterogeneous Solutions
- A solution may be classified as solid, liquid or a gaseous solution.
- **Solubility:** It is defined as the amount of solute in a saturated solution per 100g of a solvent.
 - The solubility of a gas in a liquid depends upon:
 - (a) The nature of the gas and the nature of the liquid,
 - (b) The temperature of the system, and
 - (c) The pressure of the gas.
 - **Henry's Law:** The effect of pressure on the solubility of a gas in a liquid is governed by *Henry's Law*. It states that the solubility of a gas in a liquid at a given temperature is directly proportional to the partial pressure of the gas. Mathematically, $P = K_H \cdot X$ where P is the partial pressure of the gas; and X is the mole fraction of the gas in the solution and K_H is Henry's Law constant.
 - **The vapor pressure:** Vapor pressure of a liquid is the pressure exerted by its vapor when it is in dynamic equilibrium with its liquid, in a closed container.
 - **Raoult's Law:** According to Raoult's Law, the vapor pressure of a solution containing a non-volatile solute is directly proportional to the mole fraction of the solvent (X_A). The proportionality constant being the vapor pressure of the pure solvent, i.e.,

$$P \times X_A \text{ or } P = P^\circ X_A.$$
 - **Ideal solution:** A solution which obeys Raoult's Law at all concentrations and

temperature is known as an ideal solution.

Characteristics of an ideal solution:

- (a) $\Delta_{\text{sol}} V = 0$, i.e., there is no change in volume when an ideal solution is formed.
 (b) $\Delta_{\text{sol}} H = 0$; i.e., heat is neither evolved nor absorbed during the formation of an ideal solution.

The solution shows positive deviation from Raoult's Law if its vapour pressure is higher than that predicted by Raoult's Law.

The solution shows negative deviation if its vapour pressure is lower than that predicted by Raoult's Law.

Non-ideal solution: Non-ideal solutions are those solutions which do not obey Raoult's law and whose formation is accompanied by changes of heat and volume.

Colligative properties: These properties of solutions are those properties which depend only upon the number of solute particles in the solution and not on their nature. Such properties are

- (a) Relative lowering in vapour pressure,
- (b) Elevation of boiling point,
- (c) Depression of freezing point and
- (d) Osmotic pressure.

(a) Relative lowering in vapor pressure:

$$\text{Relative lowering of vapour pressure} = \frac{P_A^{\circ} - P_A}{P_A^{\circ}}$$

$$\frac{P_A^{\circ} - P_A}{P_A^{\circ}} = X_B = \frac{n_B}{n_A + n_B}$$

Thus, according to Raoult's Law, the relative lowering of vapor pressure of a solution is equal to the mole fraction of the solute.

(b) Elevation of boiling point: For a dilute solution, the elevation in boiling point is found to be proportional to the molality of the

$$\text{solution, i.e., } \Delta T_b \propto m$$

$$\text{or } \Delta T_b = K_b m$$

where ΔT_b is the elevation in boiling point, 'm' is the molality and K_b is the Molal elevation constant

(c) Depression of freezing point: The depression in freezing point (ΔT_f) is proportional to the molality of the solution.

$$\Delta T_f \propto m$$

$$\text{or } \Delta T_f = K_f m$$

Where K_f is molal depression constant (freezing point depression constant).

Osmosis: The spontaneous flow of solvent molecules from a dilute solution into a concentrated solution when the two are separated by a perfect semipermeable membrane is called osmosis.

Osmotic pressure (π): It is the pressure which must be applied to the solution side (more concentrated solution) to just prevent the passage of pure solvent into it through a semi permeable membrane. Mathematically,

$$\pi = CRT = n_B/V - RT$$

Where π is the osmotic pressure of the solution, C is the concentration of solution n_B is the number of moles of solute, V is the volume of the solution in liters, R is the gas constant, and T is the temperature on the Kelvin scale.

In case of association, observed molar mass being more than the normal, the factor 'T' has a value less than one. But in case of dissociation, the van't Hoff factor is more than one because the observed molar mass has a less value.

Isotonic solutions are those solutions which have the same osmotic pressure. Also they have same molar concentration. For isotonic solutions, $\pi_1 = \pi_2$ Also, $C_1 = C_2$

Van't Hoff factor, 'i' is used to express the extent of association or dissociation of solutes in solution. It is the ratio of the normal and observed molar masses of the solute, i. e.,

$$i = \frac{\text{Normal molar mass}}{\text{Observed molar mass}}$$

or $i = \frac{\text{Calculated molar mass}}{\text{Experimental molar mass}}$

$$\frac{\Delta p}{p_A^0} = i \frac{\Delta T_b}{K_b} M_A \times 1000$$

- Mole fraction (X) is a unitless quantity.
- Molality (m) and mole fraction are temperature independent quantities whereas
- Molarity decreases with increase in temperature.
- As the temperature increases Henry's law constant, K_H increases so the lower is the solubility of the gas in the liquid.
- 11.7% w/w Helium is added to air used by scuba divers due to its low solubility in the blood.
- Raoult's law becomes a special case of Henry's law in which K_H becomes equal to P_A^0 , i.e., vapor pressure of pure solvent.
- Azeotropes having the same composition in liquid and vapor phase and boil at a constant temperature and therefore can't be distilled.
- Azeotropes arise due to very large deviation from Raoult's law. Maximum boiling azeotropes form when solutions exhibit negative deviation from Raoult's law whereas minimum boiling azeotropes form when solutions exhibit positive deviation from Raoult's law.
- Relative lowering in vapour pressure is a colligative property but lowering in vapour pressure is not.
- Van't Hoff factor (i) is the ratio of the observed value of the colligative property in solution to the theoretically calculated value of the colligative property.
- **(a)** A non-volatile solute undergoes dissociation, then $i > 1$.
- **(b)** A non-volatile solute undergoes association, then $i < 1$
- **Relationship between relative lowering in vapour pressure elevation in b.p.-**

- **Mole fraction (X):** If the number of moles of A and B are n_A and n_B respectively, the mole fractions of A and B will be:

$$X_A = \frac{n_A}{n_A + n_B} \text{ and } X_B = \frac{n_B}{n_A + n_B}$$

$$X_A + X_B = 1$$

$$\text{Molarity (M)} = \frac{\text{Moles of solute}}{\text{Volume of solution in litres}} \text{ mol L}^{-1}$$

$$\text{Molality (m)} = \frac{\text{Moles of solute}}{\text{Mass of solvent in kilograms}} \text{ mol kg}^{-1}$$

Parts per million (ppm)

$$= \frac{\text{Number of parts of the compound}}{\text{Total number of parts of all components of the solution}} \times 10^6$$

- **Equivalent weight:**

$$\text{Equivalent weight} = \frac{\text{Atomic or molecular weight}}{\text{Valency}}$$

$$\text{Equivalent weight of an acid} = \frac{\text{Molecular weight}}{\text{Basicity}}$$

$$\text{Equivalent weight of a base} = \frac{\text{Molecular weight}}{\text{Acidity}}$$

$$\text{Equivalent weight of a salt} = \frac{\text{Molecular weight}}{\text{Total valency of the metal atom}}$$

TYPES OF SOLUTION	
Type of Solution	Common Example
Gaseous Solutions	
(i) Gas in gas	a mixture of oxygen and nitrogen gases.
(ii) Liquid in gas	chloroform vapours mixed with nitrogen gas.
(iii) Solid in gas	camphor
Liquid Solutions	
(i) Gas in liquid	Oxygen gas dissolved in water
(iii) Liquid in liquid	ethanol dissolved in water
(iii) Solid in liquid	sucrose dissolved in water
Solid Solutions	
(i) Gas in solid	solutions of hydrogen in palladium
(ii) Liquid in solid	Amalgam of mercury with sodium
(iii) Solid in solid	copper dissolved in gold

Check Yourself

1. Mole fraction of glycerin $C_3H_5(OH)_3$ in solution containing 36g of water and 46 g of glycerin is

(A) 0.46 (B) 0.40

(C) 0.20 (D) 0.36

2. Out of molality (m), molarity (M), formality (F) and mole fraction (x), those which are independent of temperature are

(A) M, m (B) F, x

(C) m, x (D) M, x

3. Which of the following condition is not satisfied by an ideal solution?

(A) $\Delta H_{\text{mixing}} = 0$ (B) $\Delta V_{\text{mixing}} = 0$

(C) Raoult's Law is obeyed

(D) Formation of an azeotropic mixture

4. The boiling point of an azeotropic mixture of water and ethanol is less than that of water and ethanol. The mixture shows

(A) No deviation from Raoult's Law.
(B) Positive deviation from Raoult's Law.

(C) Negative deviation from Raoult's Law.

(D) That the solution is unsaturated.

5. Which has the lowest boiling point at 1 atm pressure?

(A) 0.1 M KCl (B) 0.1 M Urea

(C) 0.1 M $CaCl_2$ (D) 0.1 M $AlCl_3$

Test Yourself

Question: Classify the following as amorphous or crystalline solids: Polyurethane, naphthalene, benzoic acid, Teflon, potassium nitrate, cellophane, polyvinyl chloride, fiberglass, copper

Answer: Crystalline solids: Benzoic acid, potassium nitrate, copper
amorphous solids: Polyurethane, Teflon, cellophane, polyvinyl chloride, fiberglass

Stretch Yourself

1. Why is it advised to add ethylene glycol to water in a car radiator in hill station?

2. An aqueous solution of 2% non-volatile exerts a pressure of 1.004 Bar at the normal boiling point of the solvent. What is the molar mass of the solute?

3. Give reasons, why does an azeotropic mixture distills without any change in composition?

4. Calculate the freezing point of an aqueous solution containing 10.50 g of $MgBr_2$ in 200 g of water. (Molar mass of $MgBr_2 = 184$ g) (K_f for water = 1.86 K kg mol⁻¹)

5. Which colligative property is preferred for the molar mass determination of macromolecules?



Answers

Check Yourself

Answer: 1(C); 2(C); 3(D); 4(B); 5(B)

Stretch Yourself

- Adding ethylene glycol to car reduces the freezing point of water. It is used as antifreeze in car radiators during winters.
- Hint:**

$$\frac{p_1^0 - p_1}{p_1^0} = \frac{w_2 \times M_1}{M_2 \times w_1}$$

- This happens because when an azeotrope is boiled, the vapor has the same proportions of constituents as the unboiled mixture. Because their composition is unchanged by distillation, azeotropes are also called (especially in older texts) constant boiling point mixtures.
- Given data, $W_2 = 10.5 \text{ g}$ $W_1 = 200 \text{ g}$ Molar mass of MgBr, $M_2 = 184 \text{ g}$
 K_f of water = 1.86
 Hence the change in freezing point is given by the relation,
 $\Delta T_f = (1000 \times K_f \times W_2) / (W_1 \times M_2) = (1000 \times 1.86 \times 10.5) / (200 \times 184) \Rightarrow \Delta T_f = 0.53 \text{ K}$
 Hence new freezing point, $T_f = T_0 - \Delta T_f = 273 - 0.53 = 272.47 \text{ K}$
 Hence the freezing point of the solution will be 272.47 K
- Metals are malleable and ductile whereas ionic solids are hard and brittle.