

1 Solutions


Fastrack« Revision

- **Solutions:** Solutions are homogeneous mixtures of two or more than two components. These components may be solid, liquid or in gaseous state.

In a binary solution, there are two constituents:

- **Solute:** Substance that is dissolved in another substance in lesser amount. *e.g.*, sugar, salt, etc.
- **Solvent:** Substance in which another substance is dissolved in larger amount forming a solution. *e.g.*, water, milk, etc.

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 Solvent determines the physical state in which solution exists.

► Expressing Concentration of Solutions


Concentration is the amount of solute present in the given quantity of solute or solvent.

Concentration of solution can be expressed in any of the following ways:

- **Mass percentage** $\left(\frac{w}{w}\right)$

$$\text{Mass \% of a solute} = \frac{\text{Mass of solute in the solution}}{\text{Total mass of solution}} \times 100$$


Knowledge BOOSTER

 Concentration described by mass percentage is commonly used in industrial chemical industry.

- **Volume percentage** $\left(\frac{v}{v}\right)$

$$\begin{aligned} \text{Volume \% of a solute} \\ = \frac{\text{Volume of solute}}{\text{Total volume of solution}} \times 100 \end{aligned}$$


Knowledge BOOSTER

 35% $\left(\frac{v}{v}\right)$ solution of ethylene glycol is used as an antifreeze in cars for cooling the engine.

- **Mass by volume percentage** $\left(\frac{w}{v}\right)$

$$\text{Mass by volume \% of solute} = \frac{\text{Mass of solute}}{\text{Volume of solution}} \times 100$$


Knowledge BOOSTER

 Volume percentage is commonly used in medicine and pharmacy.

► Parts per million (ppm)

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

Knowledge BOOSTER

 Concentration of pollutants in water or in atmosphere is often expressed in ppm.

► Mole Fraction (x)

Mole fraction of a component

$$= \frac{\text{Number of moles of the component}}{\text{Total number of moles of all the components}}$$

Knowledge BOOSTER


 Mole fraction is independent of temperature.

► Molarity

$$\text{Molarity (M)} = \frac{\text{Number of moles of solute}}{\text{Volume of solution (in L)}}$$

$$\text{No. of moles} = \frac{\text{Mass}}{\text{Molar mass}}$$


Knowledge BOOSTER

 Molarity varies with temperature, because volume depends on temperature.

► Molality

$$\text{Molality (m)} = \frac{\text{Number of moles of solute}}{\text{Mass of the solvent (in kg)}}$$

Knowledge BOOSTER

 Molality is independent of temperature, because mass does not depend on temperature.

► Solubility


- Maximum amount of solute that can be dissolved in 100 g of solvent to form a saturated solution at a given temperature is known as the solubility of a substance.
- A solute dissolves in a solvent if the intermolecular interactions are similar in both of them.
- A saturated solution is one in which no more solute can be dissolved at the same temperature and pressure whereas an unsaturated solution is one in which more solute can be dissolved at the same temperature.

- Solubility of solids in liquids increases with rise in temperature if the dissolution process is endothermic and solubility decreases if it is exothermic. However, there is no effect of pressure on solubility of solids in liquids.
- Solubility of gases in liquids increases with increase of pressure and increases with decrease of temperature.

- **Law of Henry:** At certain temperature for a given volume of solvent, amount of gas dissolved is directly proportional to partial pressure of gas. It can be stated as the partial pressure of the gas in vapour phase (p) is proportional to the mole fraction of the gas (χ) in the solution.

$$p = K_H \chi, \text{ where } K_H = \text{Henry's law constant}$$

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 Aquatic species are more comfortable in cold water rather than in warm water due to presence of more dissolved oxygen.

- **Vapour Pressure:** Pressure exerted by vapours over the liquid phase at equilibrium state at constant temperature is called vapour pressure.

Vapour pressure depends on nature of the liquid and temperature i.e. vapour pressure increases with increase in temperature.

- **Raoult's Law:** For a solution of volatile liquids, the partial vapour pressure of each component in the solution is directly proportional to its mole fraction.

- For component A, $p_A = p_A^0 \chi_A$

$$\text{For component B, } p_B = p_B^0 \chi_B$$

$$\text{The total pressure, } p_{\text{total}} = p_A + p_B$$

- For a solution containing non-volatile solute present in a volatile solvent, Raoult's law states that the relative lowering of vapour pressure for a solution is equal to the mole fraction of solute.

$$\frac{p^0 - p_s}{p^0} = \frac{n}{n + N}$$

where, p^0 = vapour pressure of pure solvent,

p_s = vapour pressure of solution,

n = moles of solute,

and N = moles of solvent.

- **Colligative Properties:** Certain properties of solutions depend only on the number of particles of the solute and do not depend on the nature of solute, such properties are called colligative properties.

Such properties include relative lowering of vapour pressure, depression in freezing point, elevation of boiling point and osmotic pressure of the solution.

- **Calculation of Molality from Relative Lowering of Vapour Pressure of Solution**

$$\text{Molality of solution} = \frac{p^0 - p_s}{p^0} \times \frac{1000}{M}$$

where, M = Molar mass of the solvent.

- **Calculation of Molality from Elevation in Boiling Point of Solution**

$$\begin{aligned} \text{Molality of solution} &= \frac{\Delta T_b}{K_b} \\ &= \frac{\text{Elevation in boiling point}}{\text{Molal elevation constant of solvent}} \quad \dots(1) \end{aligned}$$

and

$$K = 10 \times K_b$$

where, K_b = Molal elevation constant

From eq. (1), we have

$$\Delta T_b = K_b \times \text{Molality} = \frac{K_b \times w \times 1000}{M \times W}$$

where, w and W are weights (masses) of solute and solvent respectively, M = Molar mass (or molecular weight) of solute.

- **Relation between Elevation in Boiling Point and Relative Lowering in Vapour Pressure**

$$\Delta T_b = \frac{1000 \times K_b}{M} \times \frac{\Delta p}{p^0}$$

- **Calculation of Molality from Depression in Freezing Point of Solution**

$$\begin{aligned} \text{Molality of solution} &= \frac{\Delta T_f}{K_f} \\ &= \frac{\text{Depression in freezing point}}{\text{Molal depression constant of solution}} \quad \dots(2) \end{aligned}$$

and

$$K = 10 \times K_f$$

where, K_f = Molal depression constant

From eq. (2), we have

$$\Delta T_f = K_f \times \text{Molality} = \frac{K_f \times w \times 1000}{M \times W}$$

- **Relation between Depression in Freezing Point and Relative Lowering in Vapour Pressure**

$$\Delta T_f = \frac{1000 \times K_f}{M} \times \frac{\Delta p}{p^0}$$

- **Relation between Depression in Freezing Point and Elevation in Boiling Point**

$$\frac{\Delta T_f}{\Delta T_b} = \frac{K_f}{K_b} \quad [\text{when solution has same molality}]$$

- **Osmosis and Osmotic Pressure**

- In osmosis, there is net flow of solvent to the solution in a semi-permeable membrane.
- Osmotic pressure is the extra pressure applied to stop the flow of solvent to solution across a semi-permeable membrane.
- Osmotic pressure is a colligative property as it depends on the number of solute molecules and not on their identity.

► **Relation between Osmotic Pressure and Relative Lowering in Vapour Pressure**

$$\text{Osmotic pressure } (\pi) = \frac{\Delta p}{p^0} = \frac{dST}{M}$$

$$\text{or, } \pi = \frac{nRT}{V}$$

where, d = density of solution,

S = solution constant,

Δp = lowering in vapour pressure,

T = absolute temperature,

M = molar mass of solvent,

p^0 = vapour pressure of pure solvent.

n = number of moles,

V = volume of solution (in L),

R = gas constant.

► **Hypertonic Solution:** Its concentration is higher than that of the solution separating it by a semipermeable membrane.

► **Hypotonic Solution:** Its concentration is lower than that of the solution separating it by a semipermeable membrane.

► **Isotonic Solution:** Two solutions having same osmotic pressure at a given temperature.

► **Abnormal Molecular Mass:** For the substances undergoing association, dissociation etc. in the solution, molecular mass determined from colligative properties is different, either lower or higher, from expected value. This is known as abnormal molecular mass.

► **van't Hoff Factor:** It is the ratio of the experimental value of colligative property to the calculated value of the colligative property. It is used to find out the extent of dissociation or association.

$$\text{van't Hoff factor, } i = \frac{\text{Normal molar mass}}{\text{Abnormal molar mass}}$$

$$= \frac{\text{Total number of moles of particles after association/dissociation}}{\text{Number of moles of particles before association/dissociation}}$$

$$= \frac{\text{Observed value of the colligative property}}{\text{Calculated value of the colligative property}}$$

If $i > 1$, solute undergoes dissociation and if $i < 1$, solute undergoes association.



Practice Exercise



Multiple Choice Questions

Q 1. Which of the following is an example of a solid solution? (CBSE SQP 2021 Term-1)

- Sea water
- Sugar solution
- Smoke
- 22 carat gold

Q 2. An unknown gas 'X' is dissolved in water at 2.5 bar pressure and has mole fraction 0.04 in solution. The mole fraction of 'X' gas when the pressure of gas is doubled at the same temperature is: (CBSE 2021 Term-1)

- 0.08
- 0.04
- 0.02
- 0.92

Q 3. Mole fraction of glycerine $\text{C}_3\text{H}_5(\text{OH})_3$ in solution containing 36 g of water and 46 g of glycerine is:

- 0.46
- 0.40
- 0.20
- 0.36

Q 4. On dissolving sugar in water at room temperature, solution feels cool to touch. Under which of the following cases dissolution of sugar will be most rapid? (NCERT EXEMPLAR)

- Sugar crystals in cold water
- Sugar crystals in hot water
- Powdered sugar in cold water
- Powdered sugar in hot water

Q 5. Maximum amount of a solid solute that can be dissolved in a specified amount of a given liquid solvent does not depend upon: (NCERT EXEMPLAR)

- temperature
- nature of solute
- pressure
- nature of solvent

Q 6. The value of K_H for $\text{Ar}(g)$, $\text{CO}_2(g)$, $\text{HCHO}(g)$ and $\text{CH}_4(g)$ are 40.39, 1.67, 1.83×10^{-5} and 0.413 respectively. Arrange these gases in increasing order of solubility. (NCERT EXEMPLAR)

- $\text{HCHO} < \text{CH}_4 < \text{CO}_2 < \text{Ar}$
- $\text{HCHO} < \text{CO}_2 < \text{CH}_4 < \text{Ar}$
- $\text{Ar} < \text{CO}_2 < \text{CH}_4 < \text{HCHO}$
- $\text{Ar} < \text{CH}_4 < \text{CO}_2 < \text{HCHO}$

Q 7. Solubility of gas in liquid decreases with increase in: (CBSE 2023)

- pressure
- temperature
- volume
- number of solute molecules

Q 8. Value of Henry's constant K_H : (CBSE 2023)

- Increases with decrease in temperature
- decreases with increase in temperature
- increases with increase in temperature
- remains constant

Q 9. Identify the law which is stated as: "For any solution, the partial vapour pressure of each volatile component in the solution is directly proportional to its mole fraction." (CBSE SQP 2021 Term-1)

- Henry's law
- Raoult's law
- Dalton's law
- Gay-Lussac's law

Q 10. Which of the following formula represents Raoult's law for a solution containing non-volatile solute? (CBSE 2021 Term-1)

- $p_{\text{solute}} = p_{\text{solute}}^0 \cdot X_{\text{solute}}$
- $p = K_H X$
- $p_{\text{total}} \propto p_{\text{solvent}}$
- $p_{\text{solute}} = p_{\text{solvent}}^0 \cdot X_{\text{solvent}}$

- Q 11. If two liquids A and B form minimum boiling azeotrope at some specific composition, then: (NCERT EXEMPLAR)
- A-B interactions are stronger than those between A-A or B-B.
 - vapour pressure of solution increases because more number of molecules of liquid A and B can escape from the solution.
 - vapour pressure of solution decreases because less number of molecules of only one of the liquids escape from the solution.
 - A-B interaction are weaker than those between A-A or B-B.
- Q 12. Considering the formation, breaking and strength of hydrogen bond, predict which of the following mixtures will show a positive deviation from Raoult's law? (NCERT EXEMPLAR)
- Methanol and acetone
 - Chloroform and acetone
 - Nitric acid and water
 - Phenol and aniline
- Q 13. Which one of the following pairs will form an ideal solution? (CBSE 2021 Term-1)
- Chloroform and acetone
 - Ethanol and acetone
 - n-hexane and n-heptane
 - Phenol and aniline
- Q 14. Which one of the following pairs will not form an ideal solution? (CBSE 2023)
- Benzene and toluene
 - Nitric acid and water
 - Hexane and heptane
 - Ethyl chloride and ethyl bromide
- Q 15. An azeotropic mixture of two liquids will have a boiling point lower than either of the two liquids when it: (CBSE 2023; CBSE 2021 Term-1)
- shows a negative deviation from Raoult's law
 - forms an ideal solution
 - shows a positive deviation from Raoult's law
 - is saturated
- Q 16. On mixing 20 mL of acetone with 30 mL of chloroform, the total volume of the solution is: (CBSE 2021 Term-1)
- < 50 mL
 - = 50 mL
 - > 50 mL
 - = 10 mL
- Q 17. Which of the following condition is not satisfied by an ideal solution?
- $\Delta H_{\text{mixing}} = 0$
 - $\Delta V_{\text{mixing}} = 0$
 - Raoult's law is obeyed
 - Formation of an azeotropic mixture
- Q 18. The colligative property used for the determination of molar mass of polymers and proteins is: (CBSE 2023)
- osmotic pressure
 - depression in freezing point
 - relative lowering in vapour pressure
 - elevation in boiling point
- Q 19. Low concentration of oxygen in the blood and tissues of people living at high altitude is due to: (CBSE 2023)
- high atmospheric pressure
 - low temperature
 - low atmospheric pressure
 - both low temperature and high atmospheric pressure
- Q 20. Osmotic pressure of a solution is 0.0821 atm at a temperature of 300 K. The concentration in moles/litre will be:
- 0.33
 - 0.666
 - 0.3×10^{-2}
 - 3
- Q 21. How much ethyl alcohol must be added to 1 L of water so that the solution will freeze at -14°C ? (K_f for water = 1.86°C/mol) (CBSE SQP 2021 Term-1)
- 7.5 mol
 - 8.5 mol
 - 9.5 mol
 - 10.5 mol
- Q 22. Elevation of boiling point is inversely proportional to: (CBSE SQP 2021 Term-1)
- molal elevation constant (K_b)
 - molality (m)
 - molar mass of solute (M)
 - weight of solute (W)
- Q 23. Colligative properties depend on: (NCERT EXEMPLAR)
- the nature of the solute particles dissolved in solution
 - the number of solute particles in solution
 - the physical properties of the solute particles dissolved in solution
 - the nature of solvent particles
- Q 24. Which of the following aqueous solutions should have the highest boiling point? (NCERT EXEMPLAR)
- 1.0 M NaOH
 - 1.0 M Na_2SO_4
 - 1.0 M NH_4NO_3
 - 1.0 M KNO_3
- Q 25. In comparison to a 0.01 solution of glucose, the depression in freezing point of a 0.01 M MgCl_2 solution is: (NCERT EXEMPLAR)
- the same
 - about twice
 - about three times
 - about six times
- Q 26. At a given temperature, osmotic pressure of a concentrated solution of a substance:
- is higher than that of a dilute solution
 - is lower than that of a dilute solution
 - is same as that of a dilute solution
 - cannot be compared with osmotic pressure of dilute solution
- Q 27. When 1 mole of benzene is mixed with 1 mole of toluene, the vapour will contain: (CBSE SQP 2021 Term-1)
- (Given: Vapour pressure of benzene = 12.8 kPa and Vapour pressure of toluene = 3.85 kPa).
- equal amount of benzene and toluene as it forms an ideal solution
 - unequal amount of benzene and toluene as it forms a non-ideal solution
 - higher percentage of benzene
 - higher percentage of toluene

Q 28. The number of ions formed on dissolving one molecule of $\text{FeSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$ in water is:

(CBSE SQP 2022-23)

- a. 3 b. 4
c. 5 d. 6

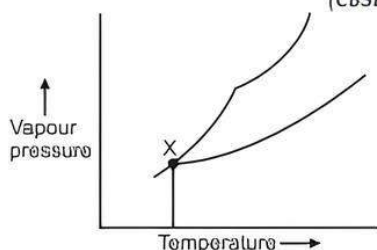
Q 29. The boiling point of a 0.2 m solution of a non-electrolyte in water is:

(K_b for water = $0.52 \text{ K kg mol}^{-1}$) (CBSE 2021 Term-1)

- a. 100°C b. 100.52°C
c. 100.104°C d. 100.26°C

Q. 30. In the following diagram, point 'X' represents:

(CBSE 2021 Term-1)



- a. boiling point of solution
b. freezing point of solvent
c. boiling point of solvent
d. freezing point of solution

Q 31. A compound $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ undergoes complete dissociation in water. The van't Hoff factor 'i' is:

(CBSE 2023)

- a. 9 b. 6 c. 3 d. 4

Q 32. A compound undergoes complete tetramerisation in a given organic solvent. The van't Hoff factor 'i' is:

(CBSE 2023)

- a. 4.0 b. 0.25 c. 0.125 d. 2.0



Assertion & Reason Type Questions

Directions (Q. Nos. 33-42): Each of the following questions consists of two statements, one is Assertion (A) and the other is Reason (R). Give answer:

- Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
- Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
- Assertion (A) is true but Reason (R) is false.
- Assertion (A) is false but Reason (R) is true.

Q 33. Assertion (A): Molarity of a solution in liquid state changes with temperature.

Reason (R): The volume of a solution changes with change in temperature. (NCERT EXEMPLAR)

Q 34. Assertion(A): Molarity of a solution changes with temperature.

Reason (R): Molarity is a colligative property.

(CBSE SQP 2021 Term-1)

Q 35. Assertion (A): In an ideal solution, $\Delta_{\text{mix}} H$ is zero.

Reason (R): In an ideal solution, A-B interactions are lower than A-A and B-B interactions.

Q 36. Assertion (A): A solution of phenol and aniline will show negative deviations from Raoult's law.

Reason (R): In case of negative deviations from Raoult's law, A-B forces are stronger than A-A and B-B forces.

Q 37. Assertion (A): The solutions which show large positive deviations from Raoult's law form maximum boiling azeotropes.

Reason (R): 95% aqueous solution of ethanol is minimum boiling azeotrope.

Q 38. Assertion (A): When methyl alcohol is added to water, boiling point of water increases.

Reason (R): When a non-volatile solute is added to a volatile solvent, elevation in boiling point is observed. (NCERT EXEMPLAR)

Q 39. Assertion (A): Elevation in boiling point is a colligative property.

Reason (R): The lowering of vapour pressure of solution causes elevation in boiling point.

(CBSE 2023)

Q 40. Assertion (A): When NaCl is added to water, a depression in freezing point is observed.

Reason (R): The lowering of vapour pressure of a solution causes depression in the freezing point.

(CBSE 2023, NCERT EXEMPLAR)

Q 41. Assertion (A): Osmotic pressure is a colligative property.

Reason (R): Osmotic pressure is proportional to the molality. (CBSE 2023)

Q 42. Assertion (A): When a solution is separated from the pure solvent by a semipermeable membrane, the solvent molecules pass through it from pure solvent side to the solution side.

Reason (R): Diffusion of solvent occurs from a region of high concentration solution to a region of low concentration solution. (NCERT EXEMPLAR)

Answers

- (d) 22 carat gold contains 22 parts of gold mixed with two parts of other metals such as copper, silver, nickel and zinc. Thus, it is an example of a solid solution.
- (a) We know that partial pressure of the gas is proportional to the mole fraction of the gas in the solution. i.e., $p \propto x$

$$\Rightarrow \frac{p_1}{p_2} = \frac{x_1}{x_2}$$

$$\Rightarrow \frac{2.5}{5} = \frac{0.04}{x_2}$$

$$\Rightarrow x_2 = 0.08.$$

3. (c) Molar mass of glycerine
 $= 12 \times 3 + 1 \times 5 + [16 \times 3 + 1 \times 3] = 92 \text{ g mol}^{-1}$
 Molar mass of water $= 1 \times 2 + 16 = 18 \text{ g mol}^{-1}$

$$\text{Moles of glycerine} = \frac{46 \text{ g}}{92 \text{ g mol}^{-1}} = 0.5 \text{ mol}$$

$$\text{Moles of water} = \frac{36 \text{ g}}{18 \text{ g mol}^{-1}} = 2 \text{ mol}$$

$$\% \text{ glycerine} = \frac{\text{moles of glycerine}}{\text{moles of glycerine} + \text{moles of water}} = \frac{0.5}{0.5 + 2} = \frac{0.5}{2.5} = 0.20$$
4. (d) powdered sugar in hot water
5. (c) Pressure does not have any significant effect on solubility of solids in liquids because solids and liquids are highly incompressible.
6. (c) Higher the value of K_H , lower will be the solubility of gas at given pressure.
7. (b) temperature
8. (c) According to Henry's law, the solubility of a gas in a liquid is directly proportional to the pressure of gas. Hence, the value of Henry's constant increases with the increase in temperature.
9. (b) Raoult's law
10. (d) $p_{\text{solute}} = p_{\text{solvent}}^0 \cdot X_{\text{solvent}}$
11. (d) Minimum boiling azeotropes show large positive deviation from Raoult's law. In this type of deviation, A-B interactions are weaker than the interaction between A-A or B-B.
12. (a) Methanol and acetone
13. (c) *n*-hexane and *n*-heptane
14. (b) The solution of nitric acid and water show large negative deviation from Raoult's law and form maximum boiling azeotrope at a specific composition. Hence, this solution will not form an ideal solution.
15. (c) Azeotropic solution that has a boiling point lower than its constituents is known as minimum boiling azeotropes. They show a large positive deviation from Raoult's law.
16. (a) A mixture of acetone and chloroform shows negative deviation from Raoult's law. Hence, a slight decrease in volume takes place.
17. (d) Formation of an azeotropic mixture
18. (a) Osmotic pressure
19. (c) At high altitudes, the partial pressure of oxygen is less than that at the ground level. This leads to low concentration of oxygen in the blood and tissues of people living at high altitudes.
20. (c) We know that, $\pi = CRT$
 $\Rightarrow 0.0821 = C \times 0.0821 \times 300$
 $\Rightarrow C = \frac{1}{300} \text{ mol/L}$
 $\Rightarrow C = 0.3 \times 10^{-2} \text{ mol/L}$
21. (a) By the formula $\Delta T_f = K_f \times m$
 $\Rightarrow \Delta T_f = K_f \frac{n_2 \times 1000}{w_1}$
 Given, $\Delta T_f = -14^\circ\text{C}$, $K_f = 1.86^\circ\text{C/mol}$
 $w_1 = 1 \text{ L} = 1000 \text{ mL}$
 Putting values,
 $\Rightarrow -14 = 1.86 \times \frac{n_2 \times 1000}{1000}$
 $\Rightarrow n_2 = 7.5 \text{ mol}$
22. (c) We know that.
 Elevation of boiling point $(\Delta T_b) \propto m$
 Also,

$$\Delta T_b = \frac{K_b \times 1000 \times \text{weight of solute}}{\text{Molar mass of solute} \times \text{weight of solvent}}$$

 Thus, $\Delta T_b \propto \frac{1}{\text{Molar mass of solute}}$
23. (b) the number of solute particles in solution
24. (b) For NaOH, $i = 2$ For Na_2SO_4 , $i = 3$
 For NH_4NO_3 , $i = 2$ For KNO_3 , $i = 2$
 $\therefore i$ is maximum for Na_2SO_4 ($i = 3$), it has the highest boiling point.
25. (c) We know that, $\Delta T_f = iK_f m$
 For glucose, $\Delta T_f(\text{glucose}) = 1 \times K_f \times 0.01 \dots (1)$
 $(\because i = 1)$
 For MgCl_2 , $\Delta T_f(\text{MgCl}_2) = 3 \times K_f \times 0.01 (\because i = 3)$
 $= 3 \times \Delta T_f(\text{glucose})$
 (from eq. (1))
 Hence, depression in freezing point of MgCl_2 is three times that of glucose.
26. (a) is higher than that of a dilute solution
27. (c) It is because benzene has higher vapour pressure than toluene, so it produces more vapours.
28. (c) 1Fe^{2+} , 2SO_4^{2-} and 2NH_4^+ ions i.e., a total of 5 ions are formed on dissolving one molecule of $\text{FeSO}_4 \cdot (\text{NH}_4)_2\text{SO}_4 \cdot 6\text{H}_2\text{O}$ in water.
29. (c) Change in boiling point $(\Delta T_b) = K_b \times m$
 $= 0.52 \times 0.2 = 0.104 \text{ K}$
 $\therefore \text{Boiling point, } T_b = 0.104 + 100 = 100.104^\circ\text{C}$
30. (d) Freezing point of solution
31. (a) When $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ dissolves in water, it completely dissociates into one Ca^{2+} ion and two Cl^- ions per formula unit. Also, each formula unit of $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ is hydrated with six water molecules which remain as water molecules in the solution. Hence, the total number of particles into which each formula unit of $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ dissociates is $1(\text{Ca}^{2+}) + 2(\text{Cl}^-) + 6(\text{H}_2\text{O}) \rightarrow 9$ particles.
 So, the van't Hoff factor for $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$ is 9.
32. (b) Since, there is complete tetramerisation, hence we have.
- $$4\text{A} \rightleftharpoons \text{A}_4$$
- $$1 - \alpha \qquad \qquad \frac{\alpha}{4}$$



$$\text{van't Hoff factor, } i = \frac{1 - \alpha + \frac{\alpha}{4}}{1} = 1 - \frac{3}{4}\alpha$$

For 100% dissociation, $\alpha = 1$

$$\therefore i = 1 - \frac{3}{4} = \frac{1}{4} = 0.25$$

33. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
34. (c) Reason is false. Molarity is not a colligative property. It is a method of expressing concentration of solution.
35. (c) In an ideal solution, A-B interactions are same as A-A and B-B interactions.
36. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
37. (d) The solutions which show a large positive deviation from Raoult's law form minimum boiling azeotrope, and 95% ethanol solution is minimum boiling azeotrope.
38. (d) Assertion (A) is false but Reason (R) is true.
Assertion is wrong because when methyl alcohol is added to water, boiling point of water decreases to hydrogen bonding.
39. (c) The lowering of vapour pressure of solution causes depression in freezing point.
40. (a) When NaCl is added to water, a depression in freezing point is observed. This is due to lowering of vapour pressure of a solution. Lowering of vapour pressure is observed due to intermolecular interaction of solvent-solute particles.
41. (c) Osmotic pressure is proportional to the molarity, C of the solution at a given temperature T .
42. (b) Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).



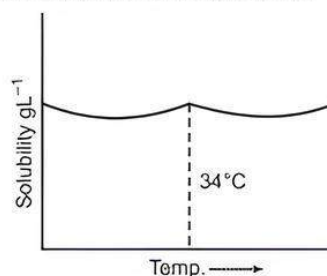
Case Study Based Questions

Case Study 1

Binary solutions can be of nine different types depending upon the nature of the solute and solvent whether solid, liquid or gas. They may be further classified as solid, liquid and gaseous solutions based on the component which acts as the solvent. However, the liquid solutions are the most important. Both solids and gases dissolve in liquids resulting in homogeneous mixtures, *i.e.* solutions. The solubility is governed by number of factors such as nature of solute and solvent, temperature, pressure etc. The concentrations of the solutions can be expressed in different ways such as normality, molarity, molality, mole fraction etc. Out of these, molality and mole fraction are better as they do not change with the change in temperature.

Read the given passage carefully and give the answer of the following questions:

Q 1. Solubility curve of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ in water with temperature is given as:



- a. solubility process is exothermic
b. solubility process is exothermic till 34°C and endothermic after 34°C
c. solubility process is endothermic till 34°C and exothermic after 34°C
d. solubility process is endothermic

Q 2. $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ is a:

- a. solution of solid in a liquid
b. solution of liquid in a solid
c. salt only and cannot be called a solution
d. co-ordination compound of copper with water molecules as the ligands

Q 3. The molality of a sulphuric acid solution in which mole fraction of water is 0.85 is:

- a. 9.80
b. 10.50
c. 10.58
d. 11.25

Q 4. Maximum amount of a solid solute that can be dissolved in a specified amount of a given liquid solvent does not depend upon:

- a. temperature
b. nature of solute
c. pressure
d. nature of solvent

Answers

1. (c) solubility process is endothermic till 34°C and exothermic after 34°C
2. (b) solution of liquid in a solid
3. (a) 9.80
4. (c) pressure

Case Study 2

The four colligative properties of the dilute solutions help in calculating the molecular mass of the solute which is often called observed molecular mass. It may be same as the theoretical molecular mass (calculated from the molecular formula) if the solute behaves normally in solution. In case, it undergoes association or dissociation, the observed molar mass gives different results. The nature of the solute in solution is expressed in terms of van't Hoff factor (i) which may be 1 (if the solute behaves normally), less than 1 (if the solute associates) and more than 1 (if the solute dissociates). The extent of association or dissociation is represented by α which is:



$$\alpha = \frac{i-1}{(1/n-1)} \quad \text{or} \quad \frac{i-1}{n-1}$$

(for association) (for dissociation)

Read the given passage carefully and give the answer of the following questions:

- Q 1. What is common in all the four colligative properties?
- Q 2. What is the expected value of van't Hoff factor for $K_4[Fe(CN)_6]$ when it completely dissociates in water?
- Q 3. What is the value of van't Hoff factor for a dilute solution of K_2SO_4 in water?

OR

In the determination of molar mass of A^+B^- using colligative property, what will be the van't Hoff factor if the solute is 40% dissociated?

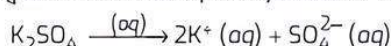
Answers

1. All of them depend upon the number of particles of the solute in the solution as well as its molar concentration.

2. $K_4[Fe(CN)_6]$ dissociates as: $4K^+ + [Fe(CN)_6]^{3-}$

$$\alpha = \frac{i-1}{(n-1)} \quad \text{or} \quad 1 = \frac{i-1}{5-1} \quad \text{or} \quad i = 4 + 1 = 5$$

3. K_2SO_4 dissociates completely in water as:

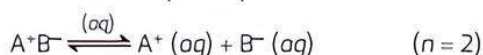


$$\alpha = \frac{i-1}{(n-1)} \quad \text{or} \quad 1 = \frac{i-1}{3-1}$$

$$\text{or } i = 2 + 1 = 3$$

OR

Dissociation of A^+B^- may be expressed as:



$$\alpha = \frac{i-1}{(n-1)}; 0.4 = \frac{i-1}{2-1}$$

$$\Rightarrow i = 1 + 0.4 = 1.4$$

Case Study 3

Henna is investigating the melting point of different salt solutions.

She makes a salt solution using 10 mL of water with a known mass of NaCl salt.

She puts the salt solution into a freezer and leaves it to freeze.

She takes the frozen salt solution out of the freezer and measures the temperature when the frozen salt solution melts.

She repeats each experiment.

S. No.	Mass of the salt used (in g)	Melting Point (in $^{\circ}\text{C}$)	
		Reading Set 1	Reading Set 2
1.	0.3	-1.9	-1.9
2.	0.4	-2.5	-2.6
3.	0.5	-3.0	-5.5

4.	0.6	-3.8	-3.8
5.	0.8	-5.1	-5.0
6.	1.0	-6.4	-6.3

Assuming the melting point of pure water as 0°C , answer the following questions:

- Q 1. One temperature in the second set of results does not fit the pattern. Which temperature is that? Justify your answer.
- Q 2. Why did Henna collect two sets of results?
- Q 3. In place of NaCl, if Henna had used glucose, what would have been the melting point of the solution with 0.6 g glucose in it?

OR

What is the predicted melting point if 1.2 g of salt is added to 10 mL of water? Justify your answer.

(CBSE SQP 2022-23)

Answers

1. The melting point of ice is the freezing point of water. We can use the depression in freezing point property in this case. 3rd reading for 0.5 g does not fit the pattern. There has to be an increase in depression of freezing point and therefore decrease in freezing point so also will there be a decrease in melting point when the amount of salt is increased but the trend is not followed in this case.

2. Henna collected two sets of results because this will help to avoid error in data collection and will give more objective data.

3. **Given:** Mass of glucose, $W_2 = 0.6 \text{ g}$

Molar mass of glucose, $M_2 = 180 \text{ g mol}^{-1}$

Mass of water, $W_1 = 10 \text{ g}$

$$\Delta T_f(\text{glucose}) = 1 \times K_f \times \frac{0.6 \times 1000}{180 \times 10} \quad \dots(1)$$

Again, molar mass of NaCl, $M_2 = 58.5 \text{ g}$

$$\Delta T_f(\text{NaCl}) = 3.8^{\circ}\text{C}$$

$$\Delta T_f(\text{NaCl}) = 2 \times K_f \times \frac{0.6 \times 1000}{58.5 \times 10} \quad \dots(2)$$

$$3.8 = 2 \times K_f \times \frac{0.6 \times 1000}{58.5 \times 10}$$

On dividing eq. (1) by eq. (2), we get

$$\frac{\Delta T_f(\text{glucose})}{3.8} = \frac{58.5}{2 \times 180}$$

$$\text{or } \Delta T_f(\text{glucose}) = 0.62$$

Freezing point or melting point $= -0.62^{\circ}\text{C}$

OR

Depression in freezing point is directly proportional to molality (mass of solute when the amount of solvent remains same)

0.3 g salt will cause depression of 1.9°C .

0.6 g salt will cause depression of 3.8°C .

1.2 g salt will cause depression of $3.8 \times 2 = 7.6^{\circ}\text{C}$

So, the predicted melting point is 7.6°C .

Very Short Answer Type Questions

Q 1. Identify which liquid will have a higher vapour pressure at 90°C if the boiling points of two liquids A and B are 140°C and 180°C respectively.

(CBSE 2020)

Ans. Liquid A will have a higher vapour pressure because $(B.P.)_A < (B.P.)_B$.

Q 2. Concentration terms such as mass percentage, ppm, mole fraction and molality are independent of temperature, however molarity is a function of temperature. Explain.

(NCERT EXEMPLAR)

Ans. The number of moles of solute present in a litre solution is defined as molarity. Since, molarity depends upon the volume of solution and volume of solution changes with change in temperature, so molarity will also change with change in temperature. On the other hand, mass does not depend upon temperature. The other given concentration terms are defined in terms of mass but not in terms of volume. So, these concentration terms do not change with change in temperature.

Q 3. What role does the molecular interaction play in a solution of alcohol and water?

(NCERT EXERCISE)

Ans. Strong hydrogen bonds are present among alcohol molecules just like water. So when these (alcohol and water) are mixed, the molecular interaction becomes weaker. Thus, they show positive deviation from ideal behaviour. As a consequence, the vapour pressure of solution is higher and boiling point is lower in comparison to water and alcohol.

Q 4. Why do gases always tend to be less soluble in liquids as the temperature is raised?

(NCERT EXEMPLAR)

Ans. Dissolution of gas in liquid is an exothermic process. Thus, according to Le-Chatelier's principle, the equilibrium shifts in backward direction on increasing the temperature. Therefore, gases always tend to be less soluble on raising the temperature.

Q 5. At low pressure and high temperature, water evaporates rapidly, why?

Ans. At low pressure and high temperature, the kinetic energy of water molecules increases. Due to this, more molecules leave the water surface and gets converted into vapour phase. That's why, evaporation of water occurs rapidly.

Q 6. Why is the vapour pressure of an aqueous solution of glucose lower than that of water?

(NCERT EXEMPLAR)

Ans. Evaporation is a surface process. Availability of more surface area is responsible for more vaporisation of water. In pure water, complete liquid surface is covered with water molecules. When a non-volatile solute like glucose is dissolved in water, the fraction occupied by solvent molecules at the solvent surface decreases because some place (fraction) is occupied

by glucose molecules. Consequently, the number of solvent molecules leaving the surface reduces and hence, vapour pressure of aqueous solution of glucose decreases.

Q 7. How does sprinkling of salt help in clearing the snow covered roads in hilly areas? Explain the phenomenon involved in the process.

(NCERT EXEMPLAR)

Ans. When salt is sprinkled on the snow covered roads, snow from the surface starts melting because sprinkling of a non-volatile substance like salt depresses the freezing point of water and hence, it helps in clearing the snow from the roads.

Q 8. Explain gram-molecular depression constant.

Ans. The depression in freezing point, when 1 gram-molecule of a non-volatile and non-electrolyte substance is dissolved in 100 gram of solvent, is called the gram-molecular or molar depression constant. It is represented as K_{100} and its unit is $\text{K mol}^{-1} 100 \text{ g}$.

Q 9. What is semipermeable membrane?

Ans. Semipermeable Membranes (SPM) are natural or synthetic continuous sheets or films which contain a network of submicroscopic holes or pores. Parchment paper, egg shell membrane, copper ferrocyanide are semipermeable membranes.

Short Answer Type-I Questions

Q 1. What do you mean by mole-fraction? Explain with example.

Ans. **Mole-fraction:** The ratio of number of moles of a constituent to the total number of moles of solute and solvent present in the solution is called the mole fraction of that constituent. It is represented by χ (chi).

Suppose a solution contains n_A mole of solute and n_B mole of solvent, then

$$\text{Mole fraction of solute } (\chi_A) = \frac{n_A}{n_A + n_B} \quad \dots(1)$$

$$\text{Mole fraction of solvent } (\chi_B) = \frac{n_B}{n_A + n_B} \quad \dots(2)$$

The sum of mole fractions of all the constituents present in a solution is one. i.e.,

$$\chi_A + \chi_B = \frac{n_A}{n_A + n_B} + \frac{n_B}{n_A + n_B} = 1$$

For a binary solution, if we know the mole fraction of one constituent, then we can calculate the mole fraction of other constituent by subtracting the mole fraction of former from one.

Example: For a binary solution, mole fraction χ_A and χ_B are related in the following manner:

$$\chi_A = 1 - \chi_B \quad \text{or} \quad \chi_B = 1 - \chi_A$$

Mole fraction is independent of temperature.

Q 2. Define the following terms:

(i) **Colligative properties** (ii) **Molality (m).**

Ans. (i) Colligative Properties: The physical properties of solutions which depend only on the number of solute particles in a particular volume of the solution, are called colligative properties. These properties do not have any relation with their chemical composition, structure and nature. These properties increase on increasing the number of particles in the solution. In these properties, ions of an electrolyte behave like particles.

(ii) **Molality (m):** It is defined as the number of moles of the solute per kilogram of the solvent.

$$\text{Molality (m)} = \frac{\text{Moles of solute}}{\text{Mass of solvent (in kg)}}$$

For example, 1.00 mol kg⁻¹ (or 1.00 m) solution of KCl means that 1 mole (74.5g) of KCl is dissolved in 1 kg of water.

Q 3. Define the following:

(i) **Ideal solutions** (ii) **Molarity (M).** (CBSE 2017)

Ans. (i) Ideal Solution: The solution that obeys Raoult's law over the entire range of concentration, are called ideal solutions.

(ii) **Molarity (M):** It is the number of moles of solute dissolved per litre of solution i.e.,

$$\text{Molarity (M)} = \frac{\text{Moles of solute}}{\text{Volume of solution (in L)}}$$

Q 4. 5.85 g sodium chloride is dissolved in 200 mL solution. Calculate the molarity of the solution.

Sol. Number of moles of NaCl in solution

$$\begin{aligned} &= \frac{\text{Mass of NaCl}}{\text{Molar mass of NaCl}} \\ &= \frac{5.85 \text{ g}}{58.5 \text{ g mol}^{-1}} = 0.1 \text{ mol} \end{aligned}$$

Volume of solution = 200 mL = 0.2 L

∴ Molarity of NaCl solution

$$\begin{aligned} &= \frac{\text{Number of moles of NaCl}}{\text{Volume of solution (in L)}} \\ &= \frac{0.1}{0.2} = 0.5 \text{ mol L}^{-1} \end{aligned}$$

Q 5. 96% sulphuric acid (W/w) has relative density 1.84. Calculate normality and molarity of this acid.

Sol. 96% H₂SO₄ (W/w) means 100 g solution contains 96g H₂SO₄.

$$\text{Volume of 100 g solution} = \frac{\text{Mass}}{\text{Density}} = \frac{100 \text{ g}}{1.84 \text{ g/mL}}$$

$$= 54.347 \text{ mL} = 0.054347 \text{ L}$$

Molarity of H₂SO₄ solution

$$= \frac{\text{Mass of H}_2\text{SO}_4 / \text{molar mass of H}_2\text{SO}_4}{\text{Volume of solution (in L)}}$$

$$= \frac{96 \text{ g} / 98 \text{ g mol}^{-1}}{0.054347 \text{ L}} = 18.024 \text{ M}$$

H₂SO₄ is a dibasic acid.

∴ Molar mass of H₂SO₄ = 2 × Equivalent weight of H₂SO₄

∴ Normality of H₂SO₄ = 2 × Molarity

$$= 2 \times 18.024 = 36.048 \text{ N}$$

Q 6. In a benzene solution, I₂ is dissolved. Mole fraction of I₂ in the solution is 0.25. Calculate the molality of the solution.

Sol. Mole fraction of solute in benzene

$$= \frac{m \times M_{\text{C}_6\text{H}_6}}{1000 + m \times M_{\text{C}_6\text{H}_6}}$$

Here, *m* = molality of solution.

*M*_{C₆H₆} = molar mass of benzene (C₆H₆)

$$= 72 + 6 = 78 \text{ g mol}^{-1}$$

On substituting the values, we have

$$0.25 = \frac{m \times 78}{1000 + m \times 78}$$

$$\begin{aligned} \text{or } 78 \text{ m} &= 1000 \times 0.25 + m \times 78 \times 0.25 \\ &= 250 + 19.5 \text{ m} \end{aligned}$$

$$\text{or } 78 \text{ m} - 19.5 \text{ m} = 250$$

$$\text{or } 58.5 \text{ m} = 250$$

$$\therefore \text{Molality of solution (m)} = \frac{250}{58.5} = 4.273 \text{ mol kg}^{-1}$$

COMMON ERROR

Students forget to write the final answer along with a proper unit.

Q 7. In 214.2 g syrup of sugar, 34.2 g sugar (C₁₂H₂₂O₁₁) is present. What will be the molality of sugar syrup? (C = 12, H = 1, O = 16).

Sol. Molar mass of sugar (C₁₂H₂₂O₁₁)

$$= 12 \times 12 + 22 \times 1 + 16 \times 11$$

$$= 144 + 22 + 176 = 342 \text{ g mol}^{-1}$$

Molality of sugar syrup

$$= \frac{\text{Mass of sugar/molar mass of sugar}}{\text{Mass of syrup of sugar (in kg)}}$$

$$= \frac{34.2 \text{ g} / 342 \text{ g mol}^{-1}}{214.2 / 1000 \text{ kg}}$$

$$= \frac{100}{214.2} \text{ m} = 0.47 \text{ mol kg}^{-1}$$

Q 8. If the density of some lake water is 1.25 g mL⁻¹ and contains 92 g of Na⁺ ions per kg of water, calculate the molality of Na⁺ ions in the lake.

$$\text{Sol. Number of moles in 92 g Na}^+ \text{ ions} = \frac{92 \text{ g}}{23 \text{ g mol}^{-1}}$$

$$= 4 \text{ mol}$$

[∵ atomic mass of Na = 23 g mol⁻¹]

∴ 4 moles of Na⁺ are present in 1 kg of lake water, so according to definition, the molality of Na⁺ ions in the lake is 4 molal.

Q 9. What is Henry's law? Give one application of it.

(CBSE 2023)

Ans. Henry's law states that at a constant temperature, the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas present above the surface of liquid of solution. In its most common form, the partial pressure of the gas in vapour phase (p) is proportional to the mole fraction of the gas (χ) in the solution. It is expressed as $p = K_H \chi$ where, K_H = Henry's law constant.

Application: To increase the solubility of CO_2 in soft drinks and soda water, the bottle is sealed under high pressure.

Q 10. State Raoult's law for a solution containing non-volatile solute. What type of deviation from Raoult's law is shown by a solution of chloroform and acetone and why? (CBSE 2017)

Ans. According to Raoult's law for a solution containing non-volatile solute, the relative lowering of vapour pressure of a solution is equal to the mole fraction of the solute.

In other words, the vapour pressure of a solution of a non-volatile solute is equal to the vapour pressure of the pure solvent at that temperature multiplied by its mole fraction. Mathematically, it can be expressed as:

$$\frac{p_1^0 - p_1}{p_1^0} = \frac{n_2}{n_1 + n_2}$$

$$\text{or } \frac{p_1^0 - p_1}{p_1^0} = \frac{n_2}{n_1} \quad (\text{for dilute solutions, } n_2 \ll n_1)$$

Negative deviation due to formation of hydrogen bond between chloroform and acetone.

Q 11. Define azeotrope. What type of azeotrope is formed by negative deviation from Raoult's law? Give an example. (CBSE 2023)

Ans. Azeotrope is a binary mixture having the same composition in liquid and vapour phase and boil at a constant temperature.

Maximum boiling azeotrope is formed by negative deviation from Raoult's law. For example, nitric acid and water solution belongs to this class of azeotrope.

Q 12. What type of deviation from Raoult's law is shown by a mixture of ethanol and acetone? Give reason. (CBSE 2023)

Ans. A mixture of ethanol and acetone shows positive deviation from Raoult's law. In pure ethanol, molecules are hydrogen bonded and when acetone is added to it, the molecules get in between the most molecules and break some of the hydrogen bonds between them. Due to weakening of interactions, the mixture shows positive deviation from Raoult's law.

Q 13. The vapour pressure of pure liquid X and pure liquid Y at 25°C are 120 mm Hg and 160 mm Hg respectively. If equal moles of X and Y are mixed to form an ideal solution, calculate the vapour pressure of the solution. (CBSE 2023)

Sol. Given, $p_x^0 = 120 \text{ mm Hg}$, $p_y^0 = 160 \text{ mm Hg}$

Since equal moles of X and Y are mixed, let mole fraction of X and Y be 0.5 each.

Vapour pressure of the solution, $p_s = p_x^0 X_x + p_y^0 Y_y$

$$\therefore p_s = 120 \times 0.5 + 160 \times 0.5 \\ = 60 + 80 = 140 \text{ mm Hg}$$

Hence, the vapour pressure of the solution is 140 mm Hg.

Q 14. A solution is prepared by dissolving 10 g of non-volatile solute in 200 g of water. It has a vapour pressure of 31.84 mm Hg at 308 K. Calculate the molar mass of the solute.

(Vapour pressure of pure water at 308 K = 32 mm Hg) (CBSE 2023)

Sol. Given,

Vapour pressure of pure water, $p^0 = 32 \text{ mm Hg}$

Vapour pressure of solvent, $p = 31.84 \text{ mm Hg}$

Weight of solute, $w = 10 \text{ g}$

Molecular weight of solvent, $W = 200 \text{ g}$

Now, molar mass of solvent, $M = 2 + 16 \times 1 \\ = 18 \text{ g mol}^{-1}$

According to Raoult's law,

$$\frac{p^0 - p}{p^0} = \frac{w \times M}{m \times W} \\ \text{or } \frac{32 - 31.84}{32} = \frac{10 \times 18}{m \times 200} \\ \Rightarrow m = \frac{10 \times 18 \times 32}{200 \times 0.16} = 180 \text{ g mol}^{-1}$$

Hence, the molar mass of the solute is 180 g mol^{-1} .

Q 15. What are colligative properties? Write the colligative property which is used to find the molecular mass of macromolecules. (CBSE 2017)

Ans. **Colligative Properties:** The properties of solution which depends only on the number of solute particles, irrespective of their nature relative to the total number of particles present in the solution are known as colligative properties.

Osmotic pressure is used to find the molecular mass of macromolecules.

COMMON ERROR

The second part of the question is answered wrongly by few students.

Q 16. What is meant by elevation in boiling point? Why is it a colligative property? (CBSE 2017)

Ans. The increase in boiling point of the solvent in a solution when a non-volatile solute is added, is called elevation in boiling point.

Elevation in boiling point is a colligative property because it depends upon molality ($\Delta T_b \propto m$) i.e. the number of solute particles rather than their nature.

Q 17. What do you mean by elevation in boiling point? How is it related with molality?

Ans. The increase in boiling point of the solution when a non-volatile solute is added to a solvent is called elevation in boiling point.

Elevation in boiling point (ΔT_b) = boiling point of solution – boiling point of solvent

$$\Delta T_b = T_2 - T_1$$

Elevation in boiling point is related with the molality of solution in the following manner:

$$\text{Molality of solution (m)} = \frac{\Delta T_b}{K_b}$$

where K_b = molal elevation constant of solvent.

Q 18. Based on solute-solvent interactions, arrange the following in order of increasing solubility in *n*-octane and explain.

Cyclohexane, KCl, CH_3OH , CH_3CN . (NCERT EXERCISE)

- Ans.** (i) Cyclohexane and *n*-octane both are non-polar, so they are completely miscible in all the proportions.
 (ii) KCl is an ionic compound while *n*-octane is a non-polar compound. So, KCl does not dissolve in *n*-octane.
 (iii) CH_3OH and CH_3CN both are polar but CH_3CN is less polar than CH_3OH . Since *n*-octane (solvent) is non-polar, so solubility of CH_3CN is more than that of CH_3OH in it.

Thus, the order of solubility in *n*-octane is $\text{KCl} < \text{CH}_3\text{OH} < \text{CH}_3\text{CN} < \text{Cyclohexane}$



TiP

Be specific while writing explanation. Avoid unnecessary description.

Q 19. What do you mean by molal elevation constant? How is it related with the molality of solution?

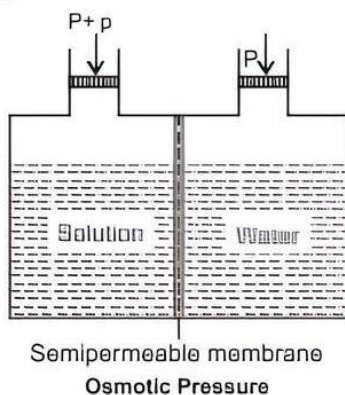
Ans. The increase in boiling point of a solvent, when one gram-molecule (mole) of a non-volatile, non-electrolyte is dissolved in 1000 g of solvent is called the molal elevation constant of the solvent. It is represented by K_b or K_{1000} . Its unit is $\text{K}\cdot\text{kg}\cdot\text{mol}^{-1}$.

$$K_b = \frac{\Delta T_b}{\text{molality (m)}}$$

Here, ΔT_b = elevation in boiling point.

Q 20. Explain osmotic pressure by giving an example.

Ans. Osmotic Pressure: It is the minimum external pressure which when applied to a solution, makes its vapour pressure equal to vapour pressure of its solvent.



Example: A vessel is divided into two equal parts by using a semi-permeable membrane. Each part of the vessel is fitted with a piston (P). Water is filled in its one part and solution is filled in the other part of the vessel. As osmosis starts, the piston fitted at the solution side moves upward. To stop this process, some external pressure is applied at the piston, so that the process of osmosis gets stopped. The external pressure applied at the piston to stop osmosis, is equal to the osmotic pressure of the solution.

Q 21. Define the following terms:

(i) **Abnormal molar mass**

(ii) **van't Hoff factor (*i*)**

(CBSE 2017)

Ans. (i) Abnormal Molar Mass: Molar mass that is either lower or higher than the expected or normal value is called abnormal molar mass. For example, all the molecules of ethanoic acid associate in benzene, then ΔT_b or ΔT_f for ethanoic acid will be half of the normal value.

(ii) **van't Hoff factor (*i*):** It is defined as the ratio of the observed value of colligative property to the calculated value of the colligative property and is used to find out the extent of dissociation or association. Mathematically, it is represented as

$$i = \frac{\text{Observed colligative property}}{\text{Calculated colligative property}}$$

Q 22. What are isotonic solutions?

Ans. Two such solutions which when separated by semipermeable membrane, shows no osmosis, are called isotonic solutions. These solutions have same osmotic pressure at a given temperature.

From van't Hoff law,

$$PV = P'V'$$

Here, $P = P'$ then

$$V = V'$$

Thus, these solutions have same gram-molecular amounts dissolved in same volumes, i.e., isotonic solutions have same molecular concentrations.

Q 23. For a 5% solution of urea (Molar Mass = 60 g/mol), calculate the osmotic pressure at 300 K. [$R = 0.0821 \text{ atm K}^{-1} \text{ mol}^{-1}$] (CBSE 2020)

Sol. Given, volume of the solution (V) = 100 mL = 0.1 L
 Weight of urea (solute), $w = 5\text{g}$
 Molar mass of urea, $M = 60 \text{ g/mol}$
 Temperature, $T = 300 \text{ K}$
 Gas constant, $R = 0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1}$
 Now, using the formula of osmotic pressure,

$$\pi = CRT$$

$$\text{or } \pi = \frac{n}{V} RT = \frac{w}{Mv} RT$$

Putting the values, we get

$$\begin{aligned} \pi &= \frac{5\text{g}}{60\text{g/mol} \times 0.1\text{L}} \times 0.0821\text{L atm K}^{-1} \text{ mol}^{-1} \times 300\text{K} \\ &= 20.5\text{ atm.} \end{aligned}$$



Q 24. Visha took two aqueous solutions—one containing 7.5g of urea (Molar mass = 60 g/mol) and the other containing 42.75 g of substance Z in 100 g of water, respectively. It was observed that both the solutions froze at the same temperature. Calculate the molar mass of Z. (CBSE 2020)

Sol. According to the question, $\Delta T_f(\text{urea}) = \Delta T_f(\text{Z})$ (1)

We know that, $\Delta T_f = \frac{K_f \times w_2 \times 1000}{w_1 \times M_2}$ (2)

Now for solution 1,

$$w_2 = 7.5 \text{ g}, M_{(\text{urea})} = 60 \text{ g/mol}$$

$$w_1 = 100 \text{ g}$$

For solution 2,

$$w_2 = 42.75 \text{ g}, M_{(\text{Z})} = ?$$

$$w_1 = 100 \text{ g}$$

Again, putting values in formula and following the eq. (1), we get

$$\frac{K_f \times 7.5 \text{ g} \times 1000}{100 \text{ g} \times 60 \text{ g/mol}} = \frac{K_f \times 42.75 \text{ g} \times 1000}{100 \text{ g} \times M_{(\text{Z})}}$$

$$\begin{aligned} \text{or } M_{(\text{Z})} &= \frac{100 \text{ g} \times 60 \text{ g/mol} \times 42.75 \text{ g} \times 1000}{7.5 \text{ g} \times 1000 \times 100 \text{ g}} \\ &= \frac{60 \text{ g/mol} \times 42.75 \text{ g}}{7.5 \text{ g}} = 342 \text{ g/mol} \end{aligned}$$

Q 25. Calculate the freezing point of a solution containing 60 g of glucose (Molar mass = 180 g mol⁻¹) in 250 g of water.

(K_f of water = 1.86 K kg mol⁻¹) (CBSE 2020)

Sol. Molality of solution,

$$m = \frac{w_2}{M_2} \times \frac{1000}{w_1}$$

where, weight of glucose, $w_2 = 60 \text{ g}$

Molar mass of glucose, $M_2 = 180 \text{ g mol}^{-1}$

Weight of solvent (water), $w_1 = 250 \text{ g}$

Putting values in the formula, we get

$$m = \frac{60}{180} \times \frac{1000}{250} = \frac{4}{3} = 1.33$$

Given, $K_f = 1.86 \text{ K kg mol}^{-1}$

Now, $\Delta T_f = K_f \cdot m = 1.86 \text{ K kg mol}^{-1} \times 1.33 \text{ m}$
= 2.47 K

Freezing point of pure water = 273.15 K

$$\therefore \text{Freezing point of solution} = 273.15 - 2.47 \text{ K} \\ = 270.68 \text{ K}$$

Q 26. A 5% solution of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ (MW = 322) is isotonic with 2% solution of non-electrolytic, non-volatile substance X. Find out the molecular weight of X. (CBSE SQP 2023-24)

Sol. Given, weight of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, $w_1 = 5 \text{ g}$

Molecular weight of $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$, $M = 322 \text{ g/mol}$

Weight of X, $w_2 = 2 \text{ g}$

For $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ $i = 3$

We know that, osmotic pressure, $\pi = iCRT$

Since, solutions are isotonic $\pi_1 = \pi_2$

$$iC_1RT = C_2RT$$

$$\text{or, } 3 \times \frac{n_1}{M_1} = \frac{n_2}{M_2}$$

$$\text{or, } \frac{3 \times 5}{322} = \frac{2}{M_2}$$

$$\text{or, } M_2 = \frac{2 \times 322}{15} = 42.9 \text{ g}$$

Hence, the molecular weight of X is 42.9 g.



Short Answer Type-II Questions

Q 1. Amongst the following compounds, identify which are insoluble, partially soluble and highly soluble in water?

- (i) Phenol, (ii) Toluene, (iii) Formic acid,
(iv) Ethylene glycol, (v) Chloroform, (vi) Pentanol.

(NCERT EXERCISE)

- Ans.** (i) Phenol is partially soluble in water. This is because, it contains polar -OH group and non-polar aromatic phenyl group. presence of which decreases its solubility in water.
(ii) Toluene is insoluble in water. This is because, it is non-polar molecule whereas water is a polar molecule. [Like dissolves like]
(iii) Formic acid is highly soluble in water as it can form hydrogen bonds with water.
(iv) Ethylene glycol is highly soluble in water as it can form hydrogen bonds with water.
(v) Chloroform being an organic liquid, is insoluble in water.
(vi) Pentanol is partially soluble in water because it contains a polar -OH group and a large non-polar hydrocarbon (C_5H_{11} -) part.

Q 2. A solution of ethyl alcohol in water is 46% by weight. Calculate mole fraction of ethyl alcohol and water in the solution. (C = 12, H = 1, O = 16).

Sol. 46% by weight ethyl alcohol solution means it contains 46 g ethyl alcohol and $100 - 46 = 54 \text{ g}$ water.
Molar mass of $\text{H}_2\text{O} = 2 \times 1 + 16 = 18 \text{ g mol}^{-1}$

$$\therefore \text{Moles of } \text{H}_2\text{O} = \frac{\text{Mass of } \text{H}_2\text{O}}{\text{Molar mass of } \text{H}_2\text{O}}$$

$$= \frac{54 \text{ g}}{18 \text{ g mol}^{-1}} = 3 \text{ mol}$$

Molar mass of ethyl alcohol ($\text{C}_2\text{H}_5\text{OH}$)

$$= 2 \times 12 + 5 \times 1 + 16 + 1 \\ = 46 \text{ g mol}^{-1}$$

$$\therefore \text{Moles of ethyl alcohol} = \frac{46 \text{ g}}{46 \text{ g mol}^{-1}} = 1 \text{ mol}$$

Total number of moles present in the solution
= moles of H_2O + moles of ethyl alcohol
= 3 + 1 = 4 mol

Mole fraction of water,

$$x_{\text{H}_2\text{O}} = \frac{\text{Moles of water}}{\text{Total number of moles present in the solution}}$$

$$= \frac{3}{4} = 0.75$$

Mole fraction of ethyl alcohol.

$$\chi_{C_2H_5OH} = \frac{\text{Moles of } C_2H_5OH}{\text{Total number of moles present in the solution}}$$

$$= \frac{1}{4} = 0.25$$

- Q 3.** A solution of glucose in water is labelled as 10% W/w. What would be the molality and mole fraction of each component in the solution. If the density of solution is 1.2 g mL^{-1} , then what shall be the molarity of the solution? (NCERT EXERCISE)

Sol.



TiP

Students should remember that molality is a mass based concept and molarity is a volume based concept.

10% (W/w) glucose solution means it contains 10 g glucose in 100 g solution or $100 - 10 = 90 \text{ g}$ solvent or water $\approx 0.090 \text{ kg}$ water.

$$\text{Number of moles of } 10 \text{ g glucose} = \frac{10}{180} \text{ mol}$$

$$= 0.0555 \text{ mol}$$

$$\text{Number of moles of } H_2O \text{ in } 90 \text{ g } H_2O = \frac{90}{18} = 5 \text{ mol}$$

$$(i) \text{ Molality} = \frac{\text{Mass of glucose}}{\text{Mass of water (in kg)}} = \frac{0.0555 \text{ mol}}{0.090 \text{ kg}}$$

$$\approx 0.617 \text{ mol kg}^{-1}$$

(ii) Mole fraction of glucose.

$$\chi_{\text{glucose}} = \frac{0.0555 \text{ mol}}{5 + 0.0555} \approx 0.011$$

$$\chi_{H_2O} \approx 11 - 0.01 \approx 0.89$$

(iii) Volume of 100 g solution

$$= \frac{100}{1.2} \text{ mL} = 83.33 \text{ mL} = 0.08333 \text{ L}$$

$$\text{Molarity} = \frac{0.0555}{0.08333} = 0.67 \text{ M}$$

- Q 4.** Answer the following questions:

(i) State Henry's law and explain why are the tanks used by scuba divers filled with air diluted with helium (11.7% helium, 56.2% nitrogen and 32.1% oxygen)?

(ii) Assume that argon exerts a partial pressure of 6 bar. Calculate the solubility of argon gas in water. (Given, Henry's law constant for argon dissolved in water, $K_H = 40 \text{ kbar}$)

(CBSE SQP 2022-23)

Ans. (i) According to Henry's law, the partial pressure of the gas in vapour phase (p) is proportional to the mole fraction of the gas (χ) in the solution.

The pressure underwater is high. so the solubility of gases in blood increases. When the diver comes to surface, the pressure decreases so the solubility also decreases causing bubbles of

nitrogen in blood. To avoid this situation and to maintain the same partial pressure of nitrogen underwater too, the tanks used by scuba divers are filled with air diluted with helium.

- (ii) **Given:** Partial pressure exerted by argon, $p = 6 \text{ bar}$. Henry's law constant, $K_H = 40 \text{ kbar} = 40 \times 10^3 \text{ bar}$

Using Henry's law, $p = K_H \times \text{mole fraction of argon in water } (\chi)$

$$\text{or, } \chi = \frac{p}{K_H}$$

$$= \frac{6}{40 \times 10^3} = 1.5 \times 10^{-4}$$

Hence, the solubility of argon gas in water is 1.5×10^{-4} .

- Q 5.** H_2S , a toxic gas with rotten egg like smell, is used for the qualitative analysis. If the solubility of H_2S in water at STP is 0.195 m, calculate Henry's law constant. (NCERT INTEXT)

Sol. Solubility of H_2S gas = 0.195 molal

$$\approx 0.195 \text{ mol in } 1 \text{ kg of water (solvent)}$$

1 kg solvent (water) = 1000 g

$$\therefore \text{Moles of solvent (water)} = \frac{1000 \text{ g}}{18 \text{ g mol}^{-1}} = 55.55 \text{ mol}$$

\therefore Mole fraction of H_2S in the solution,

$$\chi_{H_2S} = \frac{0.195}{0.195 + 55.55} = \frac{0.195}{55.745} = 0.0035$$

Pressure at STP = 0.987 bar

On applying Henry's law, we have

$$p_{H_2S} = K_H \times \chi_{H_2S}$$

$$\text{or, } K_H = \frac{p_{H_2S}}{\chi_{H_2S}} = \frac{0.987 \text{ bar}}{0.0035} \approx 282 \text{ bar}$$

- Q 6.** Henry's law constant for CO_2 in water is $1.67 \times 10^8 \text{ Pa}$ at 298 K. Calculate the quantity of CO_2 in 500 mL of soda water when packed under 2.5 atm CO_2 pressure at 298 K. (NCERT INTEXT)

Sol. Given, $K_H = 1.67 \times 10^8 \text{ Pa}$.

$$p_{CO_2} = 2.5 \text{ atm} \approx 2.5 \times 101325 \text{ Pa}$$

From Henry's law,

$$\chi_{CO_2} = \frac{p_{CO_2}}{K_H} = \frac{2.5 \times 101325 \text{ Pa}}{1.67 \times 10^8 \text{ Pa}} = 1.517 \times 10^{-3}$$

$$\therefore \frac{n_{CO_2}}{n_{H_2O} + n_{CO_2}} \approx \frac{n_{CO_2}}{n_{H_2O}} = 1.517 \times 10^{-3}$$

For 500 mL of soda water,

$$\text{volume of water} \approx 500 \text{ mL} = 500 \text{ g} \quad (\because \text{density} \approx 1 \text{ g/mL})$$

$$\text{or, } n_{H_2O} = \frac{500}{18} \approx 27.78 \text{ mol}$$

$$\frac{n_{CO_2}}{27.78} = 1.517 \times 10^{-3}$$

$$\text{or, } n_{CO_2} = 42.14 \times 10^{-3} \text{ mol}$$

Amount of CO_2 , $m_{CO_2} = \text{No. of moles} \times \text{molar mass}$

$$= 42.14 \times 10^{-3} \times 44 \text{ g}$$

$$= 1.854 \text{ g}$$

Q 7. The air is a mixture of a number of gases. The major components are oxygen and nitrogen with approximate proportion of 20% is to 79% by volume at 298 K. The water is in equilibrium with air at a pressure of 10 atm. At 298 K, if the Henry's law constants for oxygen and nitrogen are 3.30×10^7 mm and 6.51×10^7 mm respectively, calculate the composition of these gases in water.

(NCERT EXERCISE)

Sol. At equilibrium, total pressure of air with water = 10 atm.
 \therefore By volume, air contains 20% oxygen and 79% nitrogen.

\therefore Partial pressure of oxygen

$$(p_{O_2}) = \frac{20}{100} \times 10 \text{ atm} = 2 \text{ atm}$$

$$= 2 \times 760 \text{ mm} = 1520 \text{ mm.}$$

Partial pressure of nitrogen

$$(p_{N_2}) = \frac{79}{100} \times 10 \text{ atm} = 7.9 \text{ atm}$$

$$= 7.9 \times 760 \text{ mm} = 6004 \text{ mm}$$

Given. $K_H(O_2) = 3.30 \times 10^7$ mm

$K_H(N_2) = 6.51 \times 10^7$ mm

On applying Henry's law,

$$p_{O_2} = K_H \times x_{O_2}$$

$$\Rightarrow x_{O_2} = \frac{p_{O_2}}{K_H} = \frac{1520 \text{ mm}}{3.30 \times 10^7 \text{ mm}}$$

$$= 4.6 \times 10^{-5}$$

and $p_{N_2} = K_H \times x_{N_2}$

$$x_{N_2} = \frac{p_{N_2}}{K_H} = \frac{6004 \text{ mm}}{6.51 \times 10^7 \text{ mm}}$$

$$= 9.22 \times 10^{-5}$$

Q 8. Benzene and toluene form ideal solution over the entire range of composition. The vapour pressure of pure benzene and toluene at 300 K are 50.71 mm Hg and 32.06 mm Hg respectively. Calculate the mole fraction of benzene in vapour phase if 80 g of benzene is mixed with 100 g of toluene.

Sol. Molar mass of benzene (C_6H_6) = 78 g mol⁻¹

Molar mass of toluene ($C_6H_5CH_3$) = 92 g mol⁻¹

Number of moles in 80 g of benzene

$$= \frac{80}{78 \text{ g mol}^{-1}} = 1.026 \text{ mol}$$

Number of moles in 100 g of toluene

$$= \frac{100 \text{ g}}{92 \text{ g mol}^{-1}} = 1.087 \text{ mol}$$

\therefore Mole fraction of benzene in the solution

$$= \frac{1.026}{1.026 + 1.087}$$

$$= \frac{1.026}{2.113} = 0.486$$

and mole fraction of toluene = $1 - 0.486 = 0.514$

Given. $p_{\text{benzene}}^0 = 50.71 \text{ mm Hg}$

$p_{\text{toluene}}^0 = 32.06 \text{ mm Hg}$

On applying Raoult's law,

$$p_{\text{benzene}} = x_{\text{benzene}} \times p_{\text{benzene}}^0$$

$$= 0.486 \times 50.71 \text{ mm Hg}$$

$$= 24.65 \text{ mm Hg}$$

$$p_{\text{toluene}} = x_{\text{toluene}} \times p_{\text{toluene}}^0$$

$$= 0.514 \times 32.06 = 16.48 \text{ mm Hg}$$

Mole fraction of benzene in vapour phase

$$= \frac{p_{\text{benzene}}}{p_{\text{benzene}} + p_{\text{toluene}}}$$

$$= \frac{24.65}{24.65 + 16.48} = \frac{24.65}{41.13} = 0.60$$

Q 9. (i) Differentiate between ideal solution and non-ideal solution.

(ii) 30 g of urea is dissolved in 846 g of water. Calculate the vapour pressure of water for this solution if vapour pressure of pure water at 298 K is 23.8 mm Hg. (CBSE 2023)

Ans. (i) The solutions which obey Raoult's law over the entire range of concentration are called as ideal solutions. On the other hand, when a solution does not obey Raoult's law over the entire range of concentration, then it is called non-ideal solution.

(ii) Given, vapour pressure of water, $p^0 = 23.8 \text{ mm Hg}$

Mass of urea = 30 g

$$\therefore \text{Moles of urea} = \frac{\text{Mass}}{\text{Molar mass}} = \frac{30}{60} = 0.5 \text{ mol}$$

Mass of water (H_2O) = 846 g

$$\therefore \text{Moles of water} = \frac{846}{2 \times 1 + 16} = \frac{846}{18} = 47$$

From Raoult's law,

$$\frac{p^0 - p_1}{p^0} = \frac{\text{Moles of solute}}{\text{Moles of solute} + \text{Moles of solvent}}$$

$$\frac{23.8 - p_1}{23.8} = \frac{0.5}{0.5 + 47}$$

$$\Rightarrow 23.8 - p_1 = \frac{0.5 \times 23.8}{47.5} = 0.251$$

or, $p_1 = 23.8 - 0.251 = 23.549 \text{ mm Hg}$

Hence, the vapour pressure of water in the given solution is 23.549 mm of Hg.

Q 10. At any temperature the vapour pressure of a solvent is 0.416 bar. 0.5 g non-volatile non-electrolyte solid is dissolved in 42 g solvent (Molar mass = 84 g mol⁻¹). The vapour pressure of the resultant solution was found to be 0.414 bar. Calculate the molar mass of the solid.

Sol. Given, vapour pressure of solvent

$p^0 = 0.416 \text{ bar}$

Vapour pressure of solution, $p_s = 0.414 \text{ bar}$

Mass of solvent = 42 g

$$\therefore \text{Moles of solvent} = \frac{\text{Mass of solvent}}{\text{Molar mass of solvent}}$$

$$= \frac{42 \text{ g}}{84 \text{ g mol}^{-1}} = 0.5 \text{ mol}$$

Mass of solute = 0.5 g

$$\therefore \text{Moles of solute} = \frac{\text{Mass of solute}}{\text{Molar mass of solute}}$$

$$= \frac{0.5 \text{ g}}{M \text{ g mol}^{-1}} = \frac{0.5}{M} \text{ mol}$$

From Raoult's law of relative lowering of vapour pressure, we have

$$\frac{p^0 - p_s}{p^0} = \frac{\text{Moles of solute}}{\text{Moles of solvent}}$$

$$\frac{0.416 - 0.414}{0.416} = \frac{0.5 / M}{0.5}$$

$$\frac{0.002}{0.416} = \frac{1}{M}$$

$$\Rightarrow M = \frac{416}{2} = 208 \text{ g mol}^{-1}$$

Q 11. The vapour pressure of water at 293K is 17.535 mm Hg. If 25 g of glucose is dissolved in 450 g of water, calculate the vapour pressure of solute (in water) at 293 K.

Sol. Given, vapour pressure of water, $p^0 = 17.535 \text{ mm Hg}$
Mass of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) = 25 g

\therefore Moles of glucose

$$= \frac{\text{Mass}}{\text{Molar mass}} = \frac{25}{12 \times 6 + 12 + 16 \times 6} = \frac{25}{180} \text{ mol}$$

$$= 0.139 \text{ mol}$$

Mass of water (H_2O) = 450 g

$$\therefore \text{Moles of water} = \frac{450}{2 \times 1 + 16} = \frac{450}{18} = 25$$

From Raoult's law,

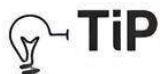
$$\frac{p^0 - p_s}{p^0} = \frac{\text{Moles of solute}}{\text{Moles of solute} + \text{Moles of solvent}}$$

$$\frac{17.535 - p_s}{17.535} = \frac{0.139}{0.139 + 25}$$

$$17.535 - p_s = \frac{0.139 \times 17.535}{25.139} = 0.097$$

$$p_s = 17.535 - 0.097$$

$$= 17.438 \text{ mm Hg}$$



Tip

Use relation $\frac{p^0 - p_s}{p_s} = \frac{w / m}{W / M}$ when molar mass is calculated and use relation $\frac{p^0 - p_s}{p_s} = \frac{w / m}{\frac{w}{m} + \frac{W}{M}}$ when calculation of vapour pressure is done.

Q 12. (i) What do you mean by lowering of vapour pressure? Write the equation of relative lowering of vapour pressure.

(ii) Why does the vapour pressure of solvent reduce, when a non-volatile solute is dissolved in it?

Ans. (i) Lowering of Vapour Pressure: When a non-volatile substance is dissolved in a solvent, the vapour pressure of the solvent is reduced. This is called **lowering of vapour pressure**. Lowering of vapour pressure is directly proportional to the mole fraction of solute.

Equation of Relative Lowering of Vapour Pressure:

If the vapour pressure of solvent is p^0 and the vapour pressure of the solution obtained when a solute is dissolved in the solvent is p_s , then lowering in the vapour pressure of the solvent $= p^0 - p_s$.

The ratio of lowering of vapour pressure ($p^0 - p_s$) and the vapour pressure of pure solvent (p^0) is called relative lowering of vapour pressure. For dilute solution, the value of relative lowering of vapour pressure is constant at all temperatures.

Relative lowering of vapour pressure

$$= \frac{\text{lowering of vapour pressure of solution}}{\text{vapour pressure of solvent}}$$

$$= \frac{p^0 - p_s}{p}$$

(ii) The molecules of a liquid are always in a state of motion in all the directions. Kinetic energy of the surface molecules are higher than that present in the bulk of the solution. Thus, these molecules escape from the surface in the form of vapours. This tendency of surface molecules is called escaping tendency. These vapour molecules exert a pressure over the liquid surface, which is called vapour pressure. If a non-volatile substance is added to a solvent to give a solution, the escaping tendency of surface molecules reduces. This is because the liquid (solvent) surface now has both solute and solvent molecules; thereby the fraction of the surface covered by the solvent molecules gets reduced. Thus, vapour pressure of the liquid decreases. Hence, the vapour pressure of the solution is always lower than the vapour pressure of pure solvent.

Q 13. (i) What do you mean by depression in freezing point?

(ii) How can the molecular weight of a non-volatile substance be calculated by freezing point depression method? Only give the formula.

Ans. (i) Depression in Freezing Point: When a non-volatile, non-electrolyte is dissolved in a solvent, its freezing point decreases. The decrease in freezing point is called depression in freezing point. It is directly proportional to amount (molality) of solute.

Depression in freezing point (ΔT_f)
 = Freezing point of solvent
 – Freezing point of solution

$$\Delta T_f = T_f^0 - T_f$$

- (ii) The molecular weight of a non-volatile substance can be calculated from depression in freezing point by using the following relation:

$$m = \frac{1000 \times K_f \times w}{\Delta T_f \times W}$$

where, m = molecular weight of solute

K_f = molal depression constant of solvent.

w = weight of solute,

W = weight of solvent.

ΔT_f = depression in freezing point

- Q 14. Calculate the elevation of boiling point in water by dissolving 3.0 g urea in 100 g of water. The molal elevation constant for water is $0.52 \text{ K kg mol}^{-1}$.**

Sol. Given, mass of urea (solute), $w = 3.0 \text{ g}$

and $K_b = 0.52 \text{ K kg mol}^{-1}$

Molar mass of urea (NH_2CONH_2).

$$m = 14 + 2 + 12 + 16 + 14 + 2$$

$$= 60 \text{ g mol}^{-1}$$

Mass of solvent (water).

$$W = 100 \text{ g} = \frac{100}{1000} = 0.1 \text{ kg}$$

We know that

Elevation of boiling point (ΔT_b) = $K_b \times \text{molality}$

$$= K_b \times \frac{w/m}{W(\text{kg})}$$

$$= 0.52 \text{ K kg mol}^{-1} \times \frac{3 \text{ g} / 60 \text{ g mol}^{-1}}{0.1 \text{ kg}}$$

$$= \frac{0.52 \times 3}{60 \times 0.1} \text{ K} = 0.26 \text{ K}$$

- Q 15. A solution of glucose (Molar Mass = 180 g mol^{-1}) in water has a boiling point of 100.20°C . Calculate the freezing point of the same solution. Molal constants for water K_f and K_b are $1.86 \text{ K kg mol}^{-1}$ and $0.512 \text{ K kg mol}^{-1}$ respectively.**

Sol. Given, for glucose solution, $T_b = 100.20^\circ\text{C}$,

$$K_b = 0.512 \text{ K kg mol}^{-1}$$

Now, using the formula,

$$\Delta T_b = K_b \cdot m$$

$$\text{or } m = \frac{\Delta T_b}{K_b} \quad [\because \Delta T_b = 100.20^\circ\text{C} - 100^\circ\text{C} = 0.20^\circ\text{C} = 0.20 \text{ K}]$$

$$= \frac{0.20 \text{ K}}{0.512 \text{ K kg mol}^{-1}}$$

$$= 0.390 \text{ mol kg}^{-1}$$

Again, $\Delta T_f = K_f \cdot m$

Given, $K_f = 1.86 \text{ K kg mol}^{-1}$

$$\therefore \Delta T_f = 1.86 \text{ K kg mol}^{-1} \times 0.390 \text{ mol kg}^{-1} = 0.725 \text{ K}$$

$$\text{Freezing point of the solution} = (273.15 - 0.725) \text{ K} = 272.425 \text{ K}$$

- Q 16. 9 g glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) is dissolved in 500 g of water. Find out the boiling point of the solution at a pressure of 1.013 bar.**

(K_b for water = $0.52 \text{ K kg mol}^{-1}$)

Sol. Mass of glucose, $w = 9 \text{ g}$

$$\text{Moles of glucose, } n = \frac{w}{\text{Molar mass of glucose}}$$

$$= \frac{9}{12 \times 6 + 12 + 16 \times 6} = \frac{9 \text{ g}}{180 \text{ g mol}^{-1}} = 0.05 \text{ mol}$$

Mass of water, $W = 500 \text{ g} = 0.5 \text{ kg}$

Elevation in boiling point,

$$\Delta T_b = K_b \times \frac{\text{Moles of glucose}}{\text{Mass of water}} = \frac{0.52 \text{ K kg mol}^{-1} \times 0.05 \text{ mol}}{0.5 \text{ kg}}$$

$$= 0.052 \text{ K} = 0.052^\circ\text{C}$$

Elevation in boiling point = boiling point of solution – boiling point of solvent.

$$\therefore \text{Boiling point of solution} = \Delta T_b + T_{\text{solvent}} = 0.052 + 373 \text{ K} = 373.052 \text{ K}$$

- Q 17. Calculate the mass of ascorbic acid (Molar Mass = 176 g mol^{-1}) to be dissolved in 75 g of acetic acid to lower its freezing point by 1.5°C .**

($K_f = 3.9 \text{ K kg mol}^{-1}$). (NCERT INTEXT; CBSE 2020)

Sol. Molar mass of ascorbic acid ($\text{C}_6\text{H}_8\text{O}_6$)

$$= 12 \times 6 + 8 \times 1 + 6 \times 16 = 176 \text{ g mol}^{-1}$$

$$\Delta T_f = K_f \times \frac{w \times 1000}{m \times W}$$

$$w = \frac{\Delta T_f \times m \times W}{K_f \times 1000} = \frac{1.5 \times 176 \times 75}{3.9 \times 1000} = 5.07 \text{ g}$$

- Q 18. On dissolving 1.822 g organic compound (molar mass 155) in 100 g benzene, the depression in freezing point is 0.60°C . Calculate the molal depression constant of benzene.**

Sol. From depression in freezing point method.

Molal depression constant of benzene,

$$K_f = \frac{m \times \Delta T_f \times W}{1000 \times w}$$

where, w = mass of solute (organic compound)

$$= 1.822 \text{ g}$$

W = mass of solvent (benzene) = 100 g

m = molar mass of solute

(organic compound)

$$= 155 \text{ g mol}^{-1}$$

ΔT_f = depression in freezing point = 0.60°C

$$K_f = \frac{155 \times 0.60 \times 100}{1000 \times 1.822} = 5.10 \text{ K kg mol}^{-1}$$

Q 19. What is molal depression constant? On dissolving 2.25 g glucose (molar mass = 180) in 25 g of water, the depression in freezing point is 0.93°C. Calculate the molal depression constant of water.

Ans. The depression in the freezing point of a solvent, when 1 g mole of a non-electrolyte solute is dissolved in 1000 g of the solvent is called the molal depression constant (K_f) of the solvent.

From depression in freezing point method.

Molal depression constant,

$$K_f = \frac{m \times \Delta T_f \times W}{1000 \times w}$$

Here, m = molar mass of solute (glucose)

$$= 180 \text{ g mol}^{-1}$$

w = mass of solute (glucose) = 2.25 g

W = mass of solvent (water) = 25 g

ΔT_f = depression in freezing point

$$= 0.93^\circ\text{C} = 0.93 \text{ K}$$

$$K_f = \frac{180 \times 0.93 \times 25}{1000 \times 2.25} = 1.86 \text{ K kg mol}^{-1}$$

Q 20. Freezing point of 5% (by weight) solution of sugar made in water is 271 K. Calculate the freezing point of 5% solution of glucose made in water, if freezing point of pure water is 273.15 K.

Sol. 5% (by weight) sugar solution means 100 g of solution contains 5 g sugar.

\therefore Mass of water in the solution (W) = 100 – 5 = 95 g

Molar mass (m) of sugar ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) = 342 g mol⁻¹

By depression in freezing point method.

Molal depression constant of water,

$$K_f = \frac{m \times \Delta T_f \times W}{1000 \times w}$$

Here, ΔT_f = depression in freezing point

= freezing point of solvent

– freezing point of solution,

$$= 273.15 \text{ K} - 271 \text{ K} = 2.15 \text{ K}$$

$$K_f = \frac{342 \times 2.15 \times 95}{1000 \times 5} = 13.97 \text{ K kg mol}^{-1}$$

For 5% glucose solution, w = 5 g, W = 95 g,

$$K_f = 13.97 \text{ K kg mol}^{-1}$$

Molar mass of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$), m = 180 g mol⁻¹

$$\therefore \Delta T_f = \frac{1000 \times K_f \times w}{m \times W}$$

$$= \frac{1000 \times 13.97 \times 5}{180 \times 95} = 4.085 \text{ K}$$

Freezing point of glucose solution

= freezing point of water – ΔT_f

$$= 273.15 \text{ K} - 4.085 \text{ K} = 269.065 \text{ K}$$



TiP

Be careful while substituting the values in the formula.

Q 21. The boiling point of solution obtained by dissolving 6 g urea (NH_2CONH_2) in 200 g water, is 100.28°C. What will be the freezing point of this solution? For water, molal elevation constant and molal depression constant are respectively 0.52°C molal⁻¹ and 1.86°C molal⁻¹.

Sol. On dissolving 6 g urea (NH_2CONH_2) in 200 g water, the molality of obtained solution,

$$m = \frac{\text{Mass of urea/Molar mass of urea}}{\text{Mass of water (in kg)}}$$

$$= \frac{6 \text{ g}/60 \text{ g mol}^{-1}}{0.2 \text{ kg}} = 0.5 \text{ m}$$

Given, K_b = 0.52°C molal⁻¹ and K_f = 1.86°C molal⁻¹

\therefore Elevation in boiling point (ΔT_b) = $K_b \times$ molality of solution

Depression in freezing point (ΔT_f) = $K_f \times$ molality of solution.

$$\therefore \Delta T_b = 0.52 \times 0.5 = 0.26^\circ\text{C}$$

$$\Delta T_f = 1.86 \times 0.5 = 0.93^\circ\text{C}$$

Now,

$$\frac{\Delta T_b}{\Delta T_f} = \frac{0.26}{0.93}$$

or

$$\Delta T_f = \frac{0.93}{0.26} \times \Delta T_b \quad \dots(1)$$

ΔT_b = Boiling point of solution – Boiling point of solvent (water)

$$= 100.28^\circ\text{C} - 100^\circ\text{C} = 0.28^\circ\text{C}$$

$$\therefore T_f = \frac{0.93}{0.26} \times 0.28 = 1.0015^\circ\text{C}$$

$\therefore \Delta T_f$ = freezing point of solvent (water)

– freezing point of solution

$$1.0015^\circ\text{C} = 0^\circ\text{C} - \text{freezing point of solution}$$

or freezing point of solution = -1.0015°C

COMMON ERROR

Students often get confused between molal elevation constant and molal depression constant and make mistake in substituting their correct values.

Q 22. At 20°C, the osmotic pressure of 45 g per litre solution of a substance is 3.2 atmosphere. Calculate the value of solution constant. The molecular weight of the substance is 342.

Sol. Given, osmotic pressure (π) = 3.2 atm

$$\text{Concentration (C)} = 45 \text{ g/L} = \frac{45}{342} \text{ mol/L}$$

Temperature, $T = 20 + 273 = 293 \text{ K}$

\therefore Osmotic pressure of solution (π) = CST

$$3.2 = \frac{45}{342} \times 5 \times 293$$

$$\text{or } S = \frac{3.2 \times 342}{45 \times 293}$$

$$= 0.083 \text{ L atm K}^{-1} \text{ mol}^{-1}$$

Q 23. At what temperature, 5% $\left(\frac{w}{V}\right)$ solution of glucose

produces 7 atmosphere pressure?

$R = 0.0821 \text{ L-atm/K/mol}$.

Sol. 5% $\left(\frac{w}{V}\right)$ glucose solution means 100 mL of the

solution contains 5 g glucose.

\therefore Concentration of glucose solution = 5 g/100 mL
= 50 g/L

Molar concentration of glucose solution

$$(C) = \frac{\text{concentration (g/L)}}{\text{molar mass of glucose}} = \frac{50}{180} \text{ M}$$

Osmotic pressure of glucose solution $(\pi) = CST = CRT$

$\therefore S = R = 0.0821 \text{ L-atm/K/mol}$

$T = \text{Temperature} = ?$, $\pi = 7 \text{ atm}$

$$T = \frac{\pi}{CR} = \frac{7}{\frac{50}{180} \times 0.0821}$$

$$= \frac{7 \times 180}{50 \times 0.0821} \text{ K} = 306.94 \text{ K}$$

Q 24. Give reasons for the following:

- Measurement of osmotic pressure method is preferred for the determination of molar mass of macromolecules such as proteins and polymers.
- Aquatic animals are more comfortable in cold water than in warm water.
- Elevation of boiling point of 1 M KCl solution is nearly double than that of 1 M sugar solution.

(CBSE 2018, 23)

Ans. (i) The osmotic pressure method has the advantage over other methods as pressure measurement is around the room temperature and the molarity of the solution is used instead of molality.

(ii) Oxygen is present in dissolved state in water. As per Henry's law, when temperature rises solubility of a gas decreases in solvent, it means solubility of oxygen in warm water is less than cold water. This makes aquatic species respire comfortably in cold water.

(iii) Elevation in boiling point is directly proportional to 'i'. $T_b \propto i$. Now as given in the question, elevation of boiling point of 1 M KCl solution is nearly double than that of 1 M sugar solution. It is because KCl being ionic, dissociates into K^+ and Cl^- and therefore, its van't Hoff factor, i is 2 whereas for sugar solution, van't Hoff factor is 1 as it does not undergo such a dissociation.

Q 25. If osmotic pressure of water at 27°C is 0.75 atm, then calculate the amount of CaCl_2 ($i = 2.47$) dissolved in 2.5 L of water.

Ans. We know that,

Osmotic pressure $\pi = iCRT$

where C = molar concentration

$$= i \frac{n}{V} RT \quad \left(\because C = \frac{n}{V} \right)$$

$$\text{or} \quad \frac{\pi \times}{i \times R \times T}$$

$$= \frac{0.75 \text{ atm} \times 2.5 \text{ L}}{2.47 \times 0.0821 \text{ L-atm K}^{-1} \text{ mol}^{-1} \times 300 \text{ K}}$$

$$= \frac{1.875}{60.836} = 0.0308 \text{ mol CaCl}_2$$

Molar mass of $\text{CaCl}_2 = 40 + 2 \times 35.5 = 111 \text{ g mol}^{-1}$

\therefore Dissolved amount = $0.0308 \times 111 \text{ g}$
= 3.42 g

Q 26. An aqueous solution, in which 12.48 g barium chloride is dissolved in 1.0 kg of water, boils at 370.0832 K . Calculate the degree of dissociation of barium chloride.

($K_b = 0.52 \text{ K kg mol}^{-1}$, Molar mass of $\text{BaCl}_2 = 208.34 \text{ g mol}^{-1}$)

Sol. Molality of barium chloride solution

$$= \frac{\text{Mass of BaCl}_2 / \text{Molar mass of BaCl}_2}{\text{Mass of water (in kg)}}$$

$$= \frac{12.48 \text{ g} / 208.34 \text{ g mol}^{-1}}{1 \text{ kg}} = 0.0599 \text{ m}$$

We know that, $\Delta T_b = i \times K_b \times m$

where, ΔT_b = elevation in boiling point

$$= T_2 - T_1 = 373.0832 - 373$$

$$= 0.0832 \text{ K}$$

m = molality of the solution = 0.0599 m

i = van't Hoff factor

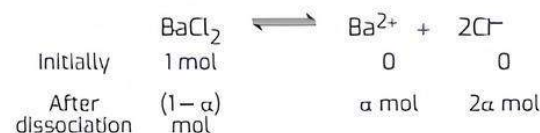
K_b = molal elevation constant of solvent (water)

$$= 0.52 \text{ K kg mol}^{-1}$$

$$\therefore 0.0832 = i \times 0.52 \times 0.0599$$

$$\text{or} \quad i = \frac{0.0832}{0.52 \times 0.0599} = 2.67$$

Suppose degree of dissociation of BaCl_2 in water is α , then



Thus, number of particles present in the solution after dissociation = $1 - \alpha + \alpha + 2\alpha = 1 + 2\alpha$

$$\therefore i = \frac{\text{Number of particles after dissociation}}{\text{Number of particles before dissociation}}$$

$$2.67 = \frac{1 + 2\alpha}{1} \quad \text{or} \quad 2\alpha = 2.67 - 1 = 1.67$$

$$\alpha = 0.835 \quad \text{or} \quad \% \alpha = 83.5\%$$

Q 27. If benzoic acid ($M = 122 \text{ g mol}^{-1}$) is associated into a dimer when dissolved in benzene and the osmotic pressure of a solution of 6.1 g of benzoic acid in 100 mL benzene is 6.5 atm at 27°C , then what is the percentage association of benzoic acid? (Given: $R = 0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1}$) (CBSE 2023)



Sol. Given, osmotic pressure, $\pi = 6.5$ atm.

Molar gas constant, $R = 0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1}$

Temperature, $T = 27^\circ\text{C} = 273 + 27 = 300 \text{ K}$

Concentration of benzoic acid in benzene

$$= 6.1 \text{ g} / 100 \text{ mL} = 61 \text{ g/L}$$

Molar concentration of benzoic acid (c)

$$= \frac{\text{Concentration (g/L)}}{\text{molar mass of benzoic acid}}$$

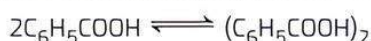
$$= \frac{61}{122} = 0.5 \text{ M}$$

We have, osmotic pressure (π) = $i \times CRT$

$$6.5 \text{ atm} = i \times 0.5 \text{ M} \times 0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1} \times 300 \text{ K}$$

$$\text{or, } i = \frac{6.5}{12.315} \Rightarrow i = 0.528$$

Now, consider the following equilibrium for the acid.



If α represents the degree of association of the solute, then we have $(1 - \alpha)$ mol of benzoic acid left in unassociated form and correspondingly $\frac{\alpha}{2}$ as associated moles of benzoic acid at equilibrium.

Therefore, total number of moles of particles at equilibrium is: $1 - \alpha + \frac{\alpha}{2} = 1 - \frac{\alpha}{2}$

$$\therefore i = 1 - \frac{\alpha}{2}$$

$$\text{or, } \frac{\alpha}{2} = 1 - 0.528 = 0.472$$

$$\text{or, } \alpha = 2 \times 0.472 = 0.944$$

Hence, degree of association of benzoic acid in benzene is 94.4%.

- Q 28.** 0.3 g of acetic acid ($M = 60 \text{ g mol}^{-1}$) dissolved in 30 g of benzene shows a depression in freezing point equal to 0.45°C . Calculate the percentage association of acid if it forms a dimer in the solution. (CBSE 2023)

(Given : K_f for benzene = $5.12 \text{ K kg mol}^{-1}$)

Sol. Given, mass of acetic acid, $w = 0.3 \text{ g}$

mass of benzene, $w = 30 \text{ g}$

$$K_f = 5.12 \text{ K kg mol}^{-1}$$

$$\Delta T_f = 0.45^\circ\text{C} = 0.45 \text{ K (depression in freezing point)}$$

We have, molar mass of acetic acid,

$$m = \frac{K_f \times 1000 \times w}{\Delta T_f \times W}$$

$$= \frac{5.12 \text{ K kg mol}^{-1} \times 0.3 \text{ g} \times 1000 \text{ g kg}^{-1}}{0.45 \text{ K} \times 30 \text{ g}}$$

$$= 113.78 \text{ g mol}^{-1}$$

Thus, experimental molar mass of acetic acid in benzene is $113.78 \text{ g mol}^{-1}$.

Now, consider the following equilibrium for the acid:



If α represents the degree of association of the solute, then we would have $(1 - \alpha)$ mol of acetic

acid in unassociated form and correspondingly $\frac{\alpha}{2}$ as associated moles of acetic acid at equilibrium.

Therefore, total number of moles of particles at

$$\text{equilibrium is: } 1 - \alpha + \frac{\alpha}{2} = 1 - \frac{\alpha}{2}$$

Thus, total number of moles of particles at equilibrium equals van't Hoff factor i .

$$\text{But } i = \frac{\text{Normal molar mass}}{\text{Abnormal molar mass}}$$

$$= \frac{60 \text{ g mol}^{-1}}{113.78 \text{ g mol}^{-1}} = 0.527$$

$$\text{Now, } 1 - \frac{\alpha}{2} = i$$

$$\text{or, } \frac{\alpha}{2} = 1 - 0.527 = 0.473$$

$$\text{or, } \alpha = 2 \times 0.473 = 0.946$$

Hence, degree of association of acetic acid in benzene is 94.6%.

- Q 29.** When 19.5 g of $\text{F} - \text{CH}_2 - \text{COOH}$ (Molar mass = 78 g mol^{-1}) is dissolved in 500 g of water, the depression in freezing point is observed to be 1°C . Calculate the degree of dissociation of $\text{F} - \text{CH}_2 - \text{COOH}$.

(Given : K_f for water = $1.86 \text{ K kg mol}^{-1}$) (CBSE 2023)

Sol. Molality of $\text{F} - \text{CH}_2 - \text{COOH}$

$$\text{Mass of } \text{F} - \text{CH}_2 - \text{COOH} / \text{Molar mass of } \text{F} - \text{CH}_2 - \text{COOH}$$

$$= \frac{\text{Mass of water}}{19.5 \text{ g} / 78 \text{ g mol}^{-1}} = 0.0005 \times 1000 \text{ mol kg}^{-1}$$

$$= 0.5 \text{ m}$$

We know that, $\Delta T_f = K_f \times \text{Molality}$

Given, K_f for water = $1.86 \text{ K kg mol}^{-1}$

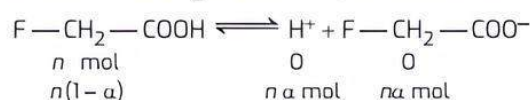
$$\therefore \Delta T_f = 1.86 \text{ K kg mol}^{-1} \times 0.5 \text{ m}$$

$$= 0.93 \text{ K}$$

$$\text{van't Hoff factor } (i) = \frac{\text{observed freezing point}}{\text{calculated freezing point}}$$

$$\text{or, } i = \frac{1 \text{ K}}{0.93 \text{ K}} = 1.075$$

When dissolved in water, $\text{F} - \text{CH}_2 - \text{COOH}$ dissociate into two ions-fluoro acetate and hydrogen ions. If x is the degree of dissociation, then we would have $n(1 - x)$ moles of the dissociated $\text{F} - \text{CH}_2 - \text{COOH}$, nx moles of $\text{F} - \text{CH}_2 - \text{COO}^-$ and, nx moles of H^+ ions.



Thus, total moles of particles are

$$n(1 - \alpha + \alpha + \alpha) = n(1 + \alpha)$$

$$i = \frac{n(1 + \alpha)}{n} = 1 + \alpha = 1.075$$

$$\text{Hence, degree of dissociation of } \text{F} - \text{CH}_2 - \text{COOH} = \alpha$$

$$= 1.075 - 1.000 = 0.075$$

Long Answer Type Questions

Q1. Define Henry's law and write its important applications. (NCERT EXERCISE)

Ans.



TiP

Write the law as stated. Don't re-frame the statement.

Henry's Law: Henry's law can be expressed as follows:

"The partial pressure of the gas in vapour phase (p) is proportional to the mole fraction of the gas (χ) in the solution, i.e.,

$$p \propto \chi \quad \text{or} \quad p = K_H \chi$$

Here, K_H is the Henry's law constant. When a mixture of gases comes in contact of a solvent then each gaseous constituent dissolves in the proportion of its partial pressure. Thus, Henry's law is applicable to each gas, irrespective to the nature of other gases present in the mixture.

Applications of Henry's Law

Some important applications of Henry's law are as follows:

- To increase the solubility of CO_2 in soft drinks and soda water, the bottle is sealed under high pressure.
- Scuba divers must cope with high concentrations of dissolved gases while breathing air at high pressure underwater. Increased pressure increases the solubility of atmospheric gases in blood. When the scuba divers come towards surface, the pressure gradually reduces. Consequently, the dissolved gases are released and leads to the formation of bubbles of nitrogen in the blood. This blocks capillaries and creates a medical condition, called **bends**, which are painful and dangerous to life. To avoid bends, as well as, the toxic effects of high concentrations of nitrogen in the blood, the tanks used by scuba divers for respiration are filled with air diluted with helium. (The composition of this air is as follows – 11.7% helium, 56.2% nitrogen and 32.1% oxygen).
- At high altitudes, the partial pressure of oxygen is less as compared to that at ground level. Thus, the concentration of oxygen in the blood and tissues of people living at high altitudes, becomes low. This makes the climbers weak and unable to think clearly. These symptoms are called anoxia.

Q 2. (i) Define Raoult's law for dilute solution and give expression of related formula. Also give its limitations.

(ii) Give the relationship between the molecular weight of solute and vapour pressure of solution.

Ans. (i) **Raoult's Law:** According to Raoult's law, "the relative lowering of vapour pressure of the solution, obtained by mixing a non-volatile solute

to the solvent, is equal to the mole fraction of the solute present in the solution", i.e.

$$\frac{p^0 - p_s}{p^0} = \frac{n}{n + N}$$

where p^0 and p_s are the vapour pressure of solvent and solution respectively; and n and N are the number of gram-molecules (or moles) of solute and solvent respectively.

For a very dilute solution, value of n is much lower in comparison to N .

$$n + N \sim N$$

Thus, here, equation $\frac{p^0 - p_s}{p^0} = \frac{n}{N}$ is used. This

equation is applicable for very dilute solutions of non-volatile solute.

Limitations of Raoult's Law:

- (a) This law is applicable only for dilute solutions. Concentrated solutions exhibit deviation from Raoult's law.



TiP

Students should be sure about the characteristics of non-ideal and ideal solutions.

- (b) It is applicable for the solutions of only non-volatile substances.
- (c) For the solutions of non-electrolytes, Raoult's law is not applicable.
- (d) Solutions of the substances that undergo either association or dissociation in the solution, do not follow Raoult's law.

(ii) Relationship between molecular weight of solute and vapour pressure of solution:

From Raoult's law,

$$\frac{p^0 - p_s}{p^0} = \frac{n}{n + N}$$

If weight (or mass) of solute is w_1 , and its molar mass is m_1 ; and weight of solvent is w_2 and its molar mass is m_2 , then

Number of gram-molecules (moles) of solute,

$$n = \frac{w_1}{m_1}$$

Number of gram-molecules (moles) of solvent,

$$N = \frac{w_2}{m_2}$$
$$\frac{p^0 - p_s}{p^0} = \frac{\frac{w_1}{m_1}}{\frac{w_1}{m_1} + \frac{w_2}{m_2}}$$

In case of dilute solution, number of gram-molecules of solute is much lower than that of the solvent. On considering it as negligible, we get

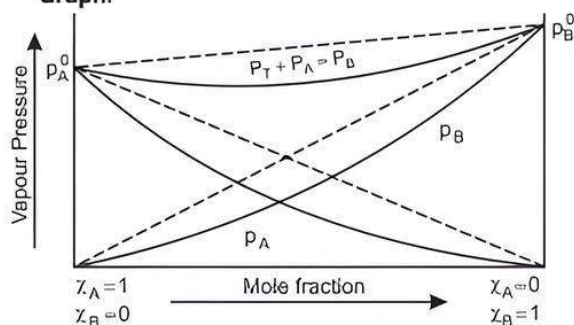
$$\frac{p^0 - p_s}{p^0} = \frac{\frac{w_1}{m_1}}{\frac{w_2}{m_2}} = \frac{w_1 m_2}{w_2 m_1}$$

$$\therefore \text{Molar mass of solute } (m_1) = \frac{p^0}{p^0 - p_s} \times \frac{w_1 \times m_2}{w_2}$$

- Q 3. (i) What type of deviation from Raoult's law is expected when phenol and aniline are mixed with each other? What change in the net volume of the mixture is expected? Graphically represent the deviation.
- (ii) The vapour pressure of pure water at a certain temperature is 23.80 mm Hg. If 1 mole of a non-volatile non-electrolytic solute is dissolved in 100 g water, calculate the resultant vapour pressure of the solution. (CBSE SQP 2023-24)

Ans. (i) Negative deviation is expected when phenol and aniline are mixed with each other. The net volume of the mixture will decrease. $\Delta V < 0$ due to stronger intermolecular interactions.

Graph:



P - x Diagram for solutions showing negative deviation from Raoult's law.

- (ii) We know that relative lowering of vapour pressure = $\frac{(p^0 - p)}{p^0} = \chi_2$ and $\chi_2 = \frac{n_2}{n_1}$

where, $n_2 = 0.1$

$$n_1 = \frac{100}{18} = 5.55$$

$$\text{Now, } \chi_2 = \frac{0.1}{(5.55 + 0.1)} = \frac{0.1}{5.65} = 0.018$$

Given, $p^0 = 23.8 \text{ mm Hg}$

$$\text{Relative lowering of vapour pressure} = \frac{(23.80 - p)}{23.80} = 0.018$$

$$\text{or, } 23.80 - p = 0.428$$

$$p = 23.80 - 0.428 = 23.37 \text{ mm Hg}$$

Hence, the resultant vapour pressure of the solution is 23.37 mm Hg.

- Q 4. (i) Write two characteristics of non-ideal solution.
- (ii) 2 g of benzoic acid ($\text{C}_6\text{H}_5\text{COOH}$) dissolved in 25 g of benzene shows a depression in freezing point equal to 1.62 K. Molal depression constant for benzene is $4.9 \text{ K kg mol}^{-1}$. What is the percentage association of acid if it forms dimer in solution? (CBSE 2019)

Ans.



TiP

Students should be sure about the characteristics of non-ideal and ideal solutions.

- (i) **Characteristics of Non-ideal Solution:**

(a) This solution does not obey Raoult's law over the entire range of concentration.

(b) $\Delta_{\text{mix}} H \neq 0$ and $\Delta_{\text{mix}} V \neq 0$

- (ii) Given, $W_2 = 2 \text{ g}$, $W_1 = 25 \text{ g}$, $\Delta T_f = 1.62 \text{ K}$

$$M_2 = \text{molar mass of benzoic acid} = 122 \text{ g mol}^{-1}$$

$$K_f (\text{benzene}) = 4.9 \text{ K kg mol}^{-1}$$

We know that,

$$\Delta T_f = \frac{i \times K_f \times W_2 \times 1000}{M_2 \times W_1} \quad \text{or} \quad i = \frac{\Delta T_f \times M_2 \times W_1}{K_f \times W_2 \times 1000}$$

Putting the values, we get

$$i = \frac{1.62 \text{ K} \times 122 \text{ g mol}^{-1} \times 25 \text{ g}}{4.9 \text{ K kg mol}^{-1} \times 2 \text{ g} \times 1000} = 0.504$$

Since, $i < 1$, therefore solute (benzoic acid) undergoes association.

As acid forms dimer in solution, so $n = 2$

Now, degree of association $\alpha = n(1 - i)$

$$= 2(1 - 0.504) = 0.992$$

Percentage of association will be 99.2%.

- Q 5. (i) Draw the graph between vapour pressure and temperature and explain the elevation in boiling point of a solvent in solution.

- (ii) Determine the osmotic pressure of a solution prepared by dissolving 25 mg of K_2SO_4 in 2 litres of water at 25°C assuming it to be completely dissociated.

(Atomic masses K = 39 u, S = 32 u, O = 16 u)

(CBSE 2019)

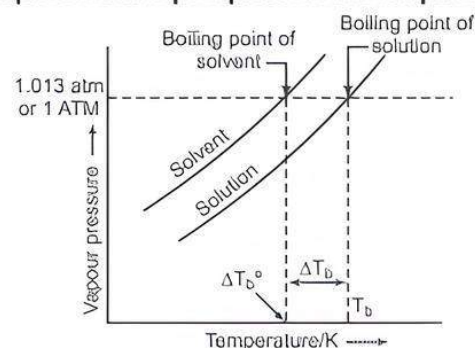
Ans.



TiP

While plotting a graph, both the independent and dependent variables must be written.

- (i) **Graph between vapour pressure and temperature:**



When a solute is added to a solvent, the vapour pressure of the solvent decreases and it becomes



equal to atmospheric pressure at a higher temperature.

- (ii) Given, mass of K_2SO_4 , $W_b = 25 \text{ mg} = 2.5 \times 10^{-2} \text{ g}$
Molar mass of K_2SO_4 , $M_b = 174 \text{ g mol}^{-1}$
 $i = n = 3$ [\because For complete dissociation, $i = n$]
 $V = 2 \text{ L}$, $T = 25^\circ\text{C} = 298 \text{ K}$
 $R = 0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1}$

We know, osmotic pressure $\pi = i \frac{W_b RT}{M_b V}$

$$\Rightarrow \pi = \frac{3 \times 2.5 \times 10^{-2} \times 0.0821 \times 298}{174 \times 2}$$

$$\pi = 5.27 \times 10^{-3} \text{ atm.}$$

- Q 6. (i) A 10% solution (by mass) of sucrose in water has a freezing point of 269.15 K. Calculate the freezing point of 10% glucose in water if the freezing point of pure water is 273.15 K.

Given: Molar mass of sucrose = 342 g mol^{-1} ,
Molar mass of glucose = 180 g mol^{-1}

- (ii) Define the following terms:

(a) Molality (m) (b) Abnormal molar mass

(CBSE 2017)

Ans. (i) For sucrose solution.

10% solution by mass means 10 g of sucrose dissolved in 90 g of water.

$$\text{Molality of sucrose solution} = \frac{W_2 \times 1000}{M_2 \times W_1}$$

Given, $W_2 = 10 \text{ g}$, $W_1 = 90 \text{ g}$, $M_2 = 342 \text{ g mol}^{-1}$

$$\text{Molality (m)} = \frac{10}{342} \times \frac{1000}{90} = 0.324 \text{ mol kg}^{-1}$$

ΔT_f for sucrose solution = $273.15 \text{ K} - 269.15 \text{ K} = 4 \text{ K}$

$$\Delta T_f = K_f m$$

$$K_f = \frac{4}{0.324} \text{ K kg mol}^{-1}$$

For glucose solution.

$W_2 = 10 \text{ g}$, $W_1 = 90 \text{ g}$,
 $M_2 = 180 \text{ g mol}^{-1}$

$$\text{Molality (M)} = \frac{10}{180} \times \frac{1000}{90} = 0.617 \text{ mol kg}^{-1}$$

$$\Delta T_f = K_f m$$

$$\therefore \Delta T_f (\text{glucose}) = \frac{4}{0.324} \times 0.617 = 7.617 \text{ K}$$

Hence, freezing point of glucose solution

$$= 273.15 - 7.617 = 265.53 \text{ K.}$$

- (ii) (a) **Molality (m):** It is defined as the number of moles of the solute per kilogram of the solvent.

$$\text{Molality (m)} = \frac{\text{Moles of solute}}{\text{Mass of solvent (in kg)}}$$

For example, 1.00 mol kg^{-1} (or 1.00 m) solution of KCl means that 1 mole (74.5) of KCl is dissolved in 1 kg of water.

(b) **Abnormal Molar Mass:** Molar mass that is either lower or higher than the expected or normal value is called abnormal molar mass. For example, all the molecules of ethanoic acid associate in benzene, then ΔT_b or ΔT_f for ethanoic acid will be half of the normal value.

- Q 7. (i) 30 g of urea ($M = 60 \text{ g mol}^{-1}$) is dissolved in 846 g of water. Calculate the vapour pressure of water for this solution if vapour pressure of pure water at 298 K is 23.8 mm Hg.

- (ii) Write two differences between ideal solutions and non-ideal solutions. (CBSE 2017)

Sol. (i) For urea, given that

$$W_B = 30 \text{ g}, M_B = 60 \text{ g mol}^{-1}$$

$$n_B = \frac{W_B}{M_B} = \frac{30}{60} = 0.5 \text{ mol}$$

For water, given that

$$W_A = 846 \text{ g}, M_A = 18 \text{ g mol}^{-1}$$

$$n_A = \frac{W_A}{M_A} = \frac{846}{18} \text{ mol} = 47 \text{ mol}$$

By the expression for vapour pressure,

$$\frac{p_A^0 - p_s}{p_A^0} = \frac{n_B}{n_A + n_B}$$

Given, vapour pressure of pure water (at 298 K)

$$= 23.8 \text{ mm Hg}$$

Vapour pressure of water (for this solution)

(p_s) = ?

$$\frac{23.8 - p_s}{23.8} = \frac{0.5}{47 + 0.5}$$

$$(47 + 0.5) (23.8 - p_s) = 23.8 \times 0.5$$

$$47.5 (23.8 - p_s) = 11.9$$

$$23.8 - p_s = \frac{11.9}{47.5} = 0.251$$

$$p_s = 23.8 - 0.251$$

$$= 23.55 \text{ mm Hg}$$

- (ii) **Difference between ideal and non-ideal solutions**

S. No.	Ideal Solution	Non-Ideal Solution
(i)	The interaction between the components are similar to those in the pure components.	The interaction between the components are different from those of the pure components.
(ii)	$p_A = p_A^0 \chi_A$ and $p_B = p_B^0 \chi_B$ i.e., they follow Raoult's law at all temperatures and concentrations.	$p_A \neq p_A^0 \chi_A$ and $p_B \neq p_B^0 \chi_B$ i.e. they do not follow Raoult's law.

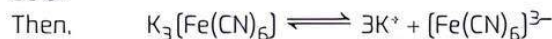
TIP

Try to give difference in tabular form if possible and provide separate points.

- Q 8. (i) What is the effect of temperature on the solubility of glucose in water?
- (ii) Ibrahim collected a 10 mL each of freshwater and ocean water. He observed that one sample labelled 'P' froze at 0°C while the other 'Q' at -1.3°C . Ibrahim forgot which of the two, 'P' or 'Q' was ocean water. Help him identify which container contains ocean water, giving rationalisation for your answer.
- (iii) Calculate van't Hoff factor for an aqueous solution of $\text{K}_3[\text{Fe}(\text{CN})_6]$ if the degree of dissociation (α) is 0.852. What will be boiling point of this solution if its concentration is 1 molal? ($K_b = 0.52 \text{ K kg/mol}$) (CBSE SQP 2023-24)

- Ans. (i) Addition of glucose to water is an endothermic reaction. According to Le Chatelier's principle, on increase in temperature, solubility will increase.
- (ii) Q is ocean water, due to the presence of salts, it freezes at lower temperature (depression in freezing point).

- (iii) Suppose degree of dissociation of $\text{K}_3[\text{Fe}(\text{CN})_6]$ be α .



Initially 1 mole 0 0

After dissociation $(1-\alpha)$ mol 3α mol α mol

Thus, number of particles present in the solution after dissociation $= 1 - \alpha + 3\alpha + \alpha = 1 + 3\alpha$

$$i = \frac{\text{Number of particles after dissociation}}{\text{Number of particles before dissociation}} = \frac{1 + 3\alpha}{1}$$

$$\text{or, } i = 1 + 3 \times 0.852 = 3.556$$

We know that $\Delta T_b = iK_b \times m$

where $K_b = 0.52 \text{ K kg/mol}$

$m = 1 \text{ molal}$

$$\Delta T_b = 3.556 \times 0.52 \times 1 = 1.85^{\circ}\text{C}$$

Also, $\Delta T_b = \text{Boiling point of solution} - \text{Boiling point of solvent (water)}$.

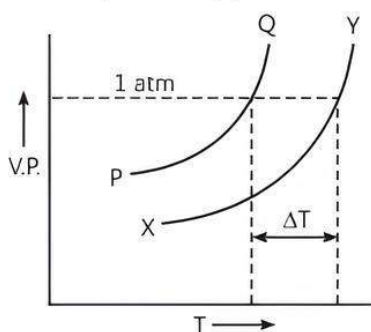
$$\therefore \text{Boiling point of solution} = 100^{\circ}\text{C} + 1.85^{\circ}\text{C} = 101.85^{\circ}\text{C}$$



Chapter Test

Multiple Choice Questions

- Q 1. The value of Henry's law constant for some gases at 293 K is given below. Arrange the gases in the increasing order of their solubility:
He: 144.97 kbar, H_2 : 69.16 kbar,
 N_2 : 76.48 kbar, O_2 : 34.86 kbar
- a. $\text{He} < \text{N}_2 < \text{H}_2 < \text{O}_2$ b. $\text{O}_2 < \text{H}_2 < \text{N}_2 < \text{He}$
c. $\text{H}_2 < \text{N}_2 < \text{O}_2 < \text{He}$ d. $\text{He} < \text{O}_2 < \text{N}_2 < \text{H}_2$
- Q 2. In the graph plotted between vapour pressure (V.P.) and temperature (T):



- a. PQ is the curve for solvent, XY is the curve of solution and ΔT is depression in freezing point.
- b. PQ is the curve for solution, XY is the curve for solvent and ΔT is elevation in boiling point.
- c. PQ is the curve for solvent, XY is the curve for solution and ΔT is molal elevation in boiling point.
- d. PQ is the curve for solvent, XY is the curve for solution and ΔT is elevation in boiling point.

- Q 3. A solution containing 10.2 g glycerine per litre is isotonic with a 2% solution of glucose. What is the molecular mass of glycerine?

a. 91.8 g b. 119.8 g c. 83.9 g d. 890.3 g

- Q 4. When acetone and chloroform are mixed together, hydrogen bonds are formed between them. Which of the following statements is correct about the solution made by mixing acetone and chloroform?

- a. On mixing acetone and chloroform will form an ideal solution.
- b. On mixing acetone and chloroform positive deviation is shown since the vapour pressure increases.
- c. On mixing acetone and chloroform negative deviation is shown since there is decrease in vapour pressure.
- d. At a specific composition acetone and chloroform will form minimum boiling azeotrope.

Assertion and Reason Type Questions

Directions (Q. Nos. 5-6): Each of the following questions consists of two statements, one is Assertion (A) and the other is Reason (R). Give answer:

- a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
- b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
- c. Assertion (A) is true but Reason (R) is false.
- d. Assertion (A) is false but Reason (R) is true.



Q 5. **Assertion (A):** 1M solution of KCl has greater osmotic pressure than 1 M solution of glucose at the same temperature.

Reason (R): In solution, KCl dissociates to produce more number of particles.

Q 6. **Assertion (A):** One molar aqueous solution is more concentrated than that of 1 molal aqueous solution.

Reason (R): Molarity is a function of temperature as volume depends on temperature.

Case Study Based Question

Q 7. Ideal and Non-ideal Solutions:

An ideal solution may be defined as the solution which obeys Raoult's law exactly over the entire range of concentration. The solutions for which vapour pressure is either higher or lower than that predicted by Raoult's law are called non-ideal solutions.

Non-ideal solutions can show either positive or negative deviations from Raoult's law depending on whether the A-B interactions in solution are stronger or weaker than A-A and B-B interactions.

Read the given passage carefully and give the answer of the following questions:

(i) For which of the following solutions ΔH_{mix} and ΔV_{mix} is negative? Can you suggest the reason for this? Acetone and aniline or ethyl alcohol and cyclohexane.

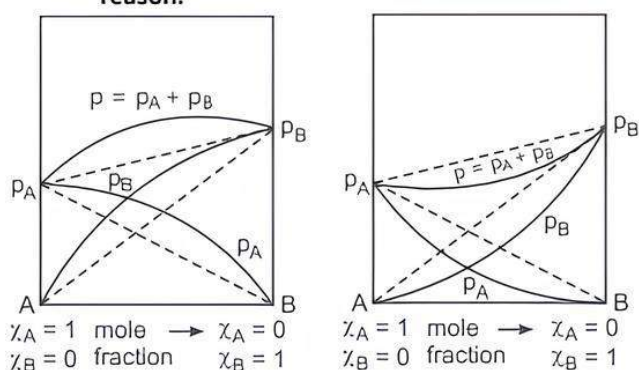
(ii) Which of the following is not true for positive deviations?

I. The A-B interactions in solution are weaker than the A-A and B-B interactions.

II. $p_A < p_A^0 \chi_A$ and $p_B < p_B^0 \chi_B$

III. Carbon tetrachloride and chloroform mixture is an example of positive deviations. What should be the correct statement?

(iii) For water and nitric acid mixture, which of the given graph is correct? Also mention the reason.



OR

What kind of deviation is shown by water-HCl mixture? Why?

Very Short Answer Type Questions

Q 8. Gas A is more soluble in water than Gas B at the same temperature. Which one of the two gases will have the higher value of K_H and why?

Q 9. Give reason why cooking is faster in pressure cooker than in cooking pan?

Short Answer Type-I Questions

Q 10. Write two differences between an ideal solution and a non-ideal solution.

Q 11. Find the freezing point of a solution containing 0.520 g glucose ($C_6H_{12}O_6$) dissolved in 80.2 g of water. (Given: K_f for water = $1.86 \text{ K kg mol}^{-1}$)

Q 12. What is van't Hoff factor? What possible values can it have if the solute molecules undergo dissociation?

Short Answer Type-II Questions

Q 13. (i) When 2.56 g of sulphur was dissolved in 100 g of CS_2 , the freezing point was lowered by 0.383 K. Calculate the formula of sulphur (S_x). [K_f for CS_2 = $3.83 \text{ K kg mol}^{-1}$, atomic mass of sulphur = 32 g mol^{-1}].

(ii) Blood cells are isotonic with 0.9% sodium chloride solution. What happens if we place blood cells in a solution containing:

(a) 1.2% sodium chloride solution?

(b) 0.4% sodium chloride solution?

Q 14. A solution containing 1.9 g per 100 mL of KCl ($M = 74.5 \text{ g mol}^{-1}$) is isotonic with a solution containing 3 g per 100 mL of urea ($M = 60 \text{ g mol}^{-1}$). Calculate the degree of dissociation of KCl solution. Assume that both the solutions have same temperature.

Q 15. A 4% solution (W/w) of sucrose ($M = 342 \text{ g mol}^{-1}$) in water has a freezing point of 271.15 K. Calculate the freezing point of 5% glucose ($M = 180 \text{ g mol}^{-1}$) in water. (Given: freezing point of pure water = 273.15 K).

Long Answer Type Questions

Q 16. (i) Calculate the freezing point of solution when 1.9 g of $MgCl_2$ ($M = 95 \text{ g mol}^{-1}$) was dissolved in 50 g of water, assuming $MgCl_2$ undergoes complete ionisation.

(K_f for water = $1.86 \text{ K kg mol}^{-1}$)

(ii) (a) Out of 1 M glucose and 2M glucose, which one has a higher boiling point and why?

(b) What happens when the external pressure applied becomes more than the osmotic pressure of solution?

Q 17. (i) State Raoult's law for a solution containing volatile components. Write two characteristics of the solution which obeys Raoult's law at all concentrations.

(ii) Why a mixture of carbon disulphide and acetone shows positive deviation from Raoult's law? What type of azeotrope is formed by this mixture?