Chapter – Solutions

Very Short Answer Questions **1 Mark**

1. Give an example of a 'liquid in solid' type solution.

Ans: Liquid in solid means solvent will be solid and the solute will be liquid. Example, mercury in sodium (amalgam).

2. Which type of solid solution will result by mixing two solid components with large differences in the sizes of their molecules?

Ans: A solid solution which will result by mixing two solid components with large difference in the sizes of their molecules is known as interstitial solid solution.

3. What is meant by semimolar and decimolar solutions?

Ans: The semimolar and decimolar terms are completely based on the molarity of the solution. Semimolar signifies the molarity of solution as $\frac{M}{2}$ and decimolar signifies the molarity of solution as $\frac{M}{10}$.

4. What will be the mole fraction of water in C_2H_5OH solution containing equal number of moles of water and C_2H_5OH?

Ans: Mole fraction of any component is given as the ratio of the respective moles of the same to the total moles of the solution. Here, if we consider x moles of water then we will have equal i.e., x moles of C_2H_5OH . Thus, Mole fraction = $\frac{x}{x+x} = \frac{1}{2} = 0.5$

5. Which of the following is a dimensionless quantity: molarity, molality or mole fraction?

Ans: Out of molarity, molality and mole fraction; mole fraction is the dimensionless quantity as it is the ratio of similar quantities i.e., moles.

6. 10 g glucose is dissolved in 400 g of solution. Calculate percentage concentration of the solution.

Ans: In general, the percentage is the ratio of a component to the total solution multiplied by 100. Thus, the percentage concentration of the solution is given as,

7. Gases tend to be less soluble in liquids as the temperature is raised. Why?

Ans: When gases are dissolved in liquid, they have high velocities due to their free movement; rising the temperature shifts the equilibrium of the reaction in the backward direction which then makes gases less soluble in liquid.

8. State the conditions which must be satisfied if an ideal solution is to be formed.

Ans: If an ideal solution is to be formed, the primary condition to be fulfilled will be a solution obeying Raoult's law. Also, the solution should be homogenous and there must not be any volumetric or thermal effects.

9. A mixture of chlorobenzene and bromobenzene forms a nearly ideal solution but a mixture of chloroform and acetone does not. Why?

Ans: In the case of a mixture of chlorobenzene and bromobenzene, there is equal interaction of the molecules hence, forming an ideal solution. Whereas, they are absent in the mixture of chloroform and acetone.

10. How is the concentration of a solute present in trace amount in a solution expressed?

Ans: When the solution has trace amounts of solute present in them, the concentration of the solute is expressed in parts per million i.e., ppm.

11. N_2 and O_2 gases have K_H values 76.48 kbar and 34.86 kbar respectively at 293 K temperature. Which one of these will have more solubility in water?

Ans: In general, lesser the value of K_H greater the solubility of a gas at the same partial pressure. Here, we can see O_2 has less value of K_H therefore, it will be more soluble than N_2 .

12. Under what condition molality and molarity of a solution are identical. Explain with suitable reasons.

Ans: The condition where the molarity and molality of the solution will be identical, is the presence of high amounts of solvent in the same i.e., dilute solutions.

13. Addition of HgI_2 to KI (aq.) shows an increase in vapor pressure. Why?

Ans: Vapor pressure is the colligative property which is completely dependent on the number of particles the solution has. When HgI_2 is added to KI, they form a complex decreasing the number of solute particles. Thus, the vapor pressure will increase.

14. What will happen to the boiling point of the solution formed on mixing two

miscible liquids showing negative deviation from Raoult's law?

Ans: When the two miscible liquids showing negative deviation from Raoult's law are mixed forming a solution, then the vapor pressure will decrease, increasing its boiling point.

15. Liquid 'Y' has higher vapor pressure than liquid 'X', which of them will have higher boiling point?

Ans: In general, high vapor pressure corresponds to the low boiling point of the liquid. Here, the vapor pressure of liquid 'X' is the lowest thus, it will have the highest boiling point.

16. When 50 mL of ethanol and 50 mL of water are mixed, predict whether the volume of the solution is equal to, greater than or less than 100 mL. Justify.

Ans: When the equal volume of ethanol and water are mixed together i.e., 50 ml each then the total volume formed will be less than 100 ml. This is because the molecules of ethanol are smaller than that of water which makes it fit themselves within the big water molecules.

17. Which type of deviation is shown by the solution formed by mixing cyclohexane and ethanol?

Ans: The solution formed by mixing cyclohexane and ethanol will show positive deviation from Raoult's law.

18. A and B liquids on mixing produce a warm solution. Which type of deviation from Raoult's law is there?

Ans: When mixing A and B produces a warm solution, then the solution will show negative deviation from Raoult's law.

19. Define cryoscopic constant (molal freezing point depression constant.)

Ans: The freezing point depression on dissolving a non – volatile solute in 1 Kg solvent is known as cryoscopic constant or molal freezing point depression constant.

20. Mention the unit of ebullioscopic constant (molal boiling point elevation constant.)

Ans: The unit of ebullioscopic constant or molal boiling point elevation constant is $\mathrm{K\ kg\ mol^{-1}}$.

21. If $\mathbf{K_f}$ for water is $\mathbf{1.86 Kkgmol^{-1}}$, what is the freezing point of 0.1 molal solution of a substance which undergoes no dissociation or association of solute?

Ans: The freezing point depression is given as,

$$\Delta T_f = iK_f m$$

Here, i = 0 as there is no dissociation or association of solute. Thus,

$$\Delta T_f = K_f m$$

$$\Delta T_f = 1.86 \times 0.1 = 0.186K$$

22. What is reverse osmosis? Give one large scale use of it.

Ans: The process takes place opposite to that of the osmosis (solvent flow towards solution through semi – permeable membrane) by applying pressure greater than osmotic pressure on the solution. The most common large scale application is desalination of seawater.

23. What is the maximum value of van't Hoff factor (i) for $\mathbf{Na_2SO_4.10H_2O}$?

Ans: The maximum value of Van't Hoff factor (i) for $Na_2SO_4.10H_2O$ will be 3.

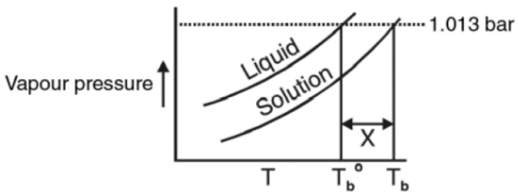
24. What is the value of van’t Hoff factor (i) if solute molecules undergo dimerisation.

Ans: The value of Van’t Hoff factor (i) for a solute who undergoes dimerization will be 0.5.

25. Under what condition is van’t Hoff factor less than one?

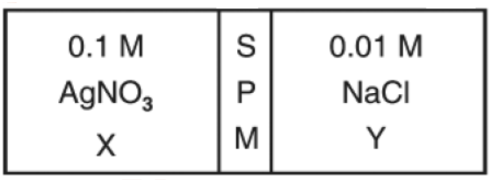
Ans: Under association of molecules only, the Van’t Hoff factor will be less than 1.

26. The Phase Diagram for pure solvent and the solution containing non – volatile solute are recorded below. The quantity indicated by ‘X’ in the figure is known as:



Ans: The quantity ‘X’ as indicated in the figure indicates ΔT_b .

27. $AgNO_3$ reaction with NaCl in aqueous solution gives white precipitate. If the two solutions are separated by a semipermeable membrane, will there be the appearance of a white ppt. in the side ‘X’ due to osmosis?



Ans: If the solutions of $AgNO_3$ and NaCl are separated by a semipermeable membrane; there will be no appearance of ppt due to the movement of only solvent particles through the membrane and not of solute particles.

Short Answer Questions **2 Marks**

1. Explain the following:

(a) Solubility of a solid in a liquid involves dynamic equilibrium.

Ans: The solubility of solid in the liquid is the maximum concentration of solute to be dissolved in solvent. Any extra solute will lead to the precipitation of the dissolved solute which leads to the attainment of dynamic equilibrium.

(b) Ionic compounds are soluble in water but are insoluble in nonpolar solvents.

Ans: In general, we know the empirical rule of 'like dissolves like'. Here, the ionic compounds are polar molecules which are soluble in water due to its polar nature.

2. Give two examples each of a solution:

(a) showing positive deviation from Raoult's Law.

Ans: The mixture of

(i) Ethanol and water.

(ii) Acetone and ethanol.

(b) showing negative deviation from Raoult's Law.

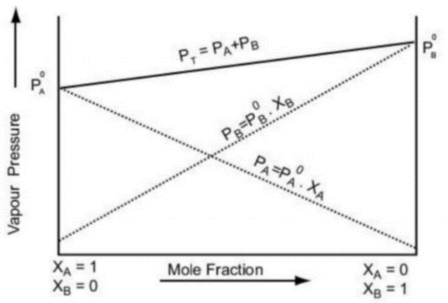
Ans: The mixture of

(i) HCl and water.

(ii) Acetone and chloroform.

3. Draw vapor pressure vs composition (in terms of mole fraction) diagram for an ideal solution.

Ans:



4. Define azeotropes with one example of each type.

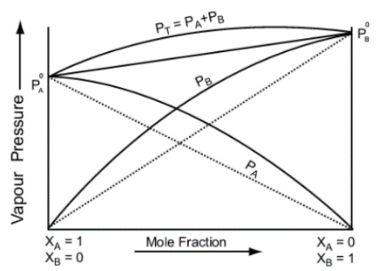
Ans: The binary mixtures of solutions that have the same composition in liquid and vapor phase having constant boiling points throughout the distillation are known as azeotropes.

(i) Minimum boiling azeotropes – mixture of water and ethanol (solutions showing positive deviation from Raoult's law).

(ii) Maximum boiling azeotropes – mixture of water and HCl (solutions showing negative deviation from Raoult's law).

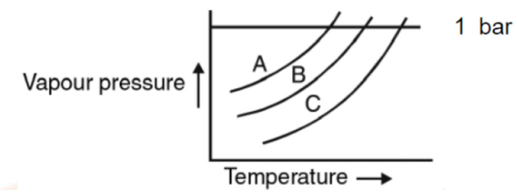
5. Draw the total vapor pressure vs. mole fraction diagram for a binary solution exhibiting non-ideal behavior with negative deviation.

Ans:



6. The vapor pressure curve for three solutions having the same non- volatile solute in the same solvent are shown. The curves are parallel to each other and

do not intersect. What is the correct order of the concentrations of the solutions? [Hint: A < B < C]



Ans: As shown in the figure, the concentration of the three solutions having the same non – volatile solute in the same solvent will be in the order of A < B < C.

7. Show that the relative lowering of vapor pressure of a solvent is a colligative property.

Ans: Colligative properties depend upon the number of solute particles in the solution. To be more precise, it is the ratio of the number of solute particles to the number of solvent particles in the solution.

Now, relative lowering of vapour pressure is given as;

$$\frac{\Delta P}{P^0} = \frac{P^0 - P}{P^0}$$

Also, by Raoult's law we know that,

$$\frac{P^0 - P}{P^0} = x$$

where, x is the mole fraction of any component.

Hence, we can say that the relative lowering of vapor pressure of a solvent is a colligative property.

8. Benzene and toluene form a nearly ideal solution. At a certain temperature, calculate the vapor pressure of a solution containing equal moles of the two substances. [Given: $P^0_{Benzene}$ = 150 mm of Hg, $P^0_{Toluene}$ = 55 mm of Hg]

Ans: In accordance with the given data, we know that,

$$P_{Solution} = P^0_{Benzene}\left[\frac{n}{n+n}\right] + P^0_{Toluene}\left[\frac{n}{n+n}\right]$$

As, we have given equal moles of both the substances. Thus,

$$P_{Solution} = \left(P^0_{Benzene} + P^0_{Toluene}\right)\times\frac{1}{2}$$

$$P_{Solution} = \left(150+55\right)\times\frac{1}{2} = 102.5 mmHg$$

9. What is meant by abnormal molecular mass? Illustrate it with suitable examples.

Ans: The molecular masses which are different theoretical molecular masses due to either association or dissociation of molecules in the solution is known as abnormal molecular masses. For example, weak electrolytes which dissociates to form ions.

10. When 1 mole of NaCl is added to 1 liter water, the boiling point increases? When 1 mole of CH_3OH is added to 1 liter water, the boiling point decreases? Suggest reasons.

Ans: When NaCl (non – volatile solute) is added to water then, the vapor pressure of the solution is lowered, increasing the boiling point. Whereas, CH_3OH is more volatile than water i.e., has more vapor pressure than that of water decreasing the boiling point.

11. Can we separate water completely from HNO_3 solution by vaporization? Justify your answer.

Ans: Water cannot be separated from nitric acid by evaporation or vaporization due to the formation of azeotropic mixture which makes the separation impossible.

12. 1 gram each of two solutes ‘A’ and ‘B’ (molar mass of A > molar mass of B) are dissolved separately in 100 g each of the same solvent. Which solute will show greater elevation in boiling point and why?

Ans: The elevation in boiling point is given as,

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

where,

n = number of moles of a component given as,

$$n = \frac{\text{mass of component}}{\text{molar mass of component}}$$

W = weight of solvent in Kgs.

In accordance to the given data and the proportionality we can say that,

$$\Delta T_b \propto \frac{1}{\text{molar mass of component}}$$

Thus, for A and B;

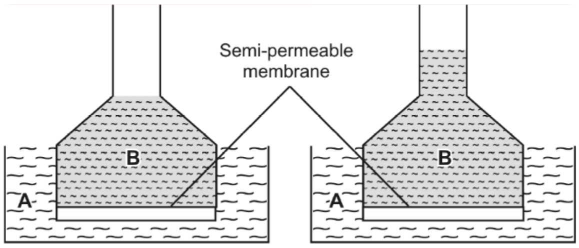
$$\Delta T_b^A = \frac{1}{M_A} \text{ and } \Delta T_b^B = \frac{1}{M_B}$$

Dividing an equation of A by B we get,

$$\frac{\Delta T_b^A}{\Delta T_b^B} = \frac{M_B}{M_A}$$

We have given that the molar mass of A > molar mass of B thus, B will show greater elevation in boiling point.

13. Examine the following illustrations and answer the following questions



(a) Identify the liquid A and liquid B (pure water or sugar solution).

Ans: Liquid A is a sugar solution and liquid B is pure water.

(b) Name the phenomenon involved in this experiment so that the level of liquid in this funnel has risen after some time.

Ans: The ongoing phenomenon is the osmosis process in which the level of liquid in the funnel has risen after some time.

14. How relative lowering in vapor pressure is related with depression in freezing point and elevation in boiling point?

Ans: The relative lowering in vapor pressure, depression in freezing point and elevation in boiling point; all the three are the colligative properties of the solutions and inter – related. The colligative properties completely depend upon the solute

particles dissolved in solvent. So, when the non – volatile solute is added to the solvent due to change in vapor pressure, all other properties change. The relative lowering in vapor pressure of solute brings depression in freezing point and elevation in boiling point of the same.

Short Answer Questions **3 Marks**

1. (a) State Henry's Law.

Ans: A gas law which states that the amount of gas dissolved in liquid is directly proportional to the partial pressure of the same gas above the liquid level when the temperature is kept constant is known as Henry's law. Mathematically, it is stated as;

$P = K_H \times C$

Where,

C = concentration of dissolved gas in the liquid

$K_H =$ Henry's law constant

P = partial pressure of the gas

(c) If O_2 is bubbled through water at 393 K, how many millimoles of O_2 gas would be dissolved in 1L of water? Assume that O_2 exerts a pressure of 0.95 bar. (Given K_H for O_2 = 46.82 bar at 393K).

Ans: In accordance with the given data and formula for Henry's law;

Concentration of gas,

$$C = \frac{P}{K_H} = \frac{0.95}{46.82} = 0.0202M$$

Now, number of moles is given as;

$n = M \times V$

$n = 0.0202 \times 1 = 0.0202 \text{moles}$

Thus, moles of O_2 dissolved in water is 20.2 millimoles.

2. Given reason for the following: –

(a) Aquatic species are more comfortable in cold waters than in warm waters.

Ans: The solubility of oxygen decreases with increase in temperature which makes aquatic organisms feel comfortable in cold water due to the high amount of dissolved oxygen.

(b) To avoid bends scuba divers use air diluted with helium.

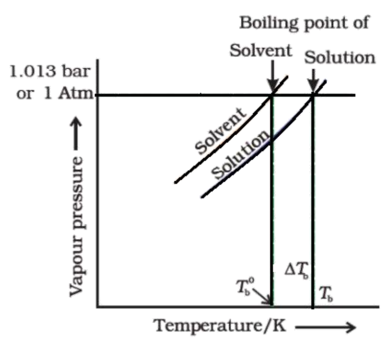
Ans: The bends during scuba diving is a condition which is very painful and dangerous for life. Thus, divers use helium as a dissolved gas in the air due to its low solubility in human blood.

(c) Cold drinks bottles are sealed under high pressure of CO_2 .

Ans: The CO_2 gas is filled in the cold drinks under high pressure and sealed as with high pressure, the solubility of gases in liquid increases.

3. Why should a solution of a non-volatile and non-electrolyte solute boil at a higher temperature? Explain with the help of a diagram. Derive the relationship between molar mass and elevation in boiling point.

Ans: The solution of a non – volatile and non – electrolyte solute should boil at high temperature as their addition lowers the vapor pressure causing them to boil only at higher temperature i.e., higher than the boiling point of pure solvent. This can be explained by the below given diagram;



The relationship between the molar mass of solute and the elevation in boiling point is given as;

Elevation in boiling point,

$$\Delta T_b = K_b m$$

where, m = molality and is stated as;

$$m = \frac{W_2}{M_2 W_1}$$

Now, putting the values in empirical equation we get,

$$M_2 = \frac{K_b W_2}{\Delta T_b W_1}$$

4. Account for the following: –

(a) $CaCl_2$ is used to clear snow from roads in hill stations.

Ans: The calcium chloride is responsible for depression in freezing point of water to an extent from where it cannot form ice hence, clearing the snow from roads.

(b) Ethylene glycol is used as an antifreeze solution in radiators of vehicles in cold countries.

Ans: The addition of ethylene glycol in car radiators lowers the freezing point of water so as to avoid bursting of lines in cold winter temperatures.

(c) The freezing point depression of 0.01 m NaCl is nearly twice that of 0.01 m glucose solution.

Ans: The sodium chloride dissociates in the solution giving two ions and glucose will never dissociate to form ions. Thus, by the relationship of freezing point depression;

$$\Delta T_f = iK_f m$$

NaCl can have nearly twice the depression in freezing point to that of glucose even though the concentrations are the same.

5. Why do colligative properties of solution of a given concentration are found to give abnormal molecular weight of solute. Explain with the help of suitable examples.

Ans: The colligative properties have been found to give abnormal molecular masses due to the presence of fact about association or dissociation of solute molecules in solvent. To help this out Van’t Hoff factor was introduced which properly explained the fact.

Solute undergoing association in the solution, Van’t Hoff factor is less then 1. Whereas, solute undergoing dissociation in the solution has Van’t Hoff factor more than 1.

Example:

$$KCl \leftrightarrow K^{+} + Cl^{-}$$

Here, a molecule of KCl gives 2 ions which gives Van’t Hoff factor (i) as 2. This will reflect in the form of abnormal molecular mass calculations for certain conditions.

6. Give reasons for the following: –

(a) RBC swells up and finally bursts when placed in 0.1% NaCl solution.

Ans: When the RBCs are placed in the 0.1% NaCl solution the water will flow inside the cells as it moves from less concentrated to more concentrated solution. At a point the cell will be so swollen, enough to burst.

(b) When fruits and vegetables that have been dried are placed in water, they slowly swell and return to original form.

Ans: The drying of fruits or vegetables causes them to become more concentrated. When these are placed in water, the phenomenon of osmosis takes place resulting in the original form of those fruits and vegetables.

(c) A person suffering from high blood pressure is advised to take less amount of table salt.

Ans: The intake of NaCl can result in an increase in the number of solutes in the body fluids. If the solute concentration is increased, the osmotic pressure increment can rupture the blood cells.

7. Glycerin, ethylene glycol and methanol are sold at the same price per kg. Which would be cheaper for preparing an antifreeze solution for the radiator of an automobile?

Ans: The antifreeze solution is responsible for lowering the freezing point of water so as to avoid the damage in the radiator in automobile system. Here, 3 solutes are needed to be compared i.e., glycerin, ethylene glycol and methanol.

According the formula;

$$\Delta T_f = K_f m$$

where, m = molality and is stated as;

$$m = \frac{W_2}{M_2 W_1}$$

We can say that the lower molar mass will give depression in freezing point and hence, the best results at lower amounts.

Molar masses are given as;

Glycerin = 92 g/mol

Ethylene glycol = 62 g/mol

Methanol = 32 g/mol

Thus, methanol will be cheaper for preparing an antifreeze solution for the radiator of an automobile.

8. Determine the correct order of the property mentioned against them:

(a) 10% glucose (p_1), 10% urea (p_2), 10% sucrose (p_3) [Osmotic pressure]

Ans: 10% urea > 10% glucose > 10% sucrose.

As, the osmotic pressure depends upon the molar concentration of the solute; urea has the highest molar concentration i.e., more moles in the solution than that of glucose and sucrose.

(b) 0.1 m NaCl, 0.1 m urea, 0.1 m $MgCl_2$ [Elevation in b.pt.]

Ans: 0.1 m $MgCl_2$ > 0.1 m NaCl > 0.1 urea.

As, the elevation in boiling point depends upon the Van't Hoff factor; $MgCl_2$ will dissociate producing the highest number of ions (3) than that of NaCl (2) and urea(0).

(c) 0.1 m $CaCl_2$, 0.1 m sucrose, 0.1 m NaCl [Depression in f.pt.]

Ans: 0.1 m $CaCl_2$ > 0.1 m NaCl > 0.1 m sucrose.

As, the depression in freezing point depends upon the Van't Hoff factor; $CaCl_2$ will dissociate producing the highest number of ions (3) than that of NaCl (2) and sucrose(0).

9. For a dilute solution containing 2.5 g of a non-volatile non-electrolyte solute in 100 g of water, the elevation in boiling point at 1 atm pressure is $2°C$. Assuming concentration of solute is much lower than the concentration of solvent, determine the vapor pressure (mm of Hg) of the solution. [Given: K_b for water = $0.76 K kg mol^{-1}$]

Ans: We have given that,

$W_2 = 2.5g$

$W_1 = 100g$

$\Delta T_b = 2°C$

$P^0 = 1atm = 760mmHg$

$K_b = 0.76 \text{Kkgmol}^{-1}$

$M_1 = 18 \text{gmol}^{-1}$

Now, we have elevation in boiling point as;

$$\Delta T_b = \frac{K_b W_2}{M_2 W_1}$$

$$\Delta T_b = \frac{0.76 \times 1000 \times 2.5}{M_2 \times 100} = 2$$

$M_2 = 9.5 \text{gmol}^{-1}$

Now, for dilute solutions;

$$\frac{P^0 - P_S}{P^0} = \frac{W_2 M_1}{M_2 W_1}$$

$$\frac{760 - P_S}{760} = \frac{2.5 \times 18}{9.5 \times 100} = 0.047$$

Thus, the vapor pressure of the solution, $P_S = 724 \text{mmHg}$.

10. 15.0 g of an unknown molecular substance was dissolved in 450 g of water. The resulting solution was found to freeze at 0.34 C

Ans: We have given that,

$W_2 = 15 \text{g}$

$W_1 = 450 \text{g}$

$\Delta T_f = 0.34 ^\circ \text{C}$

$K_f = 1.86 \text{Kkgmol}^{-1}$

Now, we have elevation in boiling point as;

$$\Delta T_f = \frac{K_f W_2}{M_2 W_1}$$

$$\Delta T_f = \frac{1.86 \times 1000 \times 15}{M_2 \times 450} = 0.34$$

$$M_2 = 182.35 \text{gmol}^{-1}$$

Long Answer Questions **5 Marks**

1. (a) What are ideal solutions? Write two examples.

Ans: The solutions obeying Raoult's law at any concentration and temperature are known as ideal solutions. For example;

(i) Benzene and toluene

(ii) Ethyl bromide and ethyl iodide.

(b) Calculate the osmotic pressure in pascals exerted by a solution prepared by dissolving 1.0g of polymer of molar mass 185000 in 450 mL of water at 37°C

Ans: We have given that,

$$W = 1.0\text{g}$$

$$M = 185000 \text{gmol}^{-1}$$

$$V = 450\text{ml} = 0.45\text{L}$$

$$T = 37 + 273 = 310\text{K}$$

$$R = 8.314 \text{Jmol}^{-1}\text{K}^{-1} = 8314 \text{PaLmol}^{-1}\text{K}^{-1}$$

Osmotic pressure is given as;

$$\pi = \frac{WRT}{MV}$$

$$\pi = \frac{8314 \times 310}{185000 \times 0.45} = 30.95\text{Pa}$$

2. (a) Describe a method of determining molar mass of a non - volatile solute from vapor pressure lowering.

Ans: There is very general method of determining molar mass of a non – volatile solute from vapor pressure.

By Raoult's law;

$$\frac{P^0 - P_S}{P^0} = x$$

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

If $n_2 << n_1$ then,

$$\frac{P^0 - P_S}{P^0} = \frac{n_2}{n_1}$$

Thus,

$$\frac{P^0 - P_S}{P^0} = \frac{W_2 M_1}{M_2 W_1}$$

From this we can easily determine the M_2 .

(b) How much urea (mol. mass 60 g/mol) must be dissolved in 50g of water so that the vapor pressure at the room temperature is reduced by 25%? Also calculate the molality of the solution obtained.

Ans: Given that,

$W_1 = 50\text{g}$

$M_1 = 18\text{gmol}^{-1}$

$M_2 = 60 \text{gmol}^{-1}$

The relative lowering in vapor pressure is given as,

$$\frac{P^0 - P_S}{P^0} = \frac{W_2 M_1}{M_2 W_1}$$

This is reduced to 25% which can be given as;

$$0.25 = \frac{W_2 \times 18}{50 \times 60}$$

$$\therefore W_2 = 41.67\text{g}$$

Molality is given as;

$$m = \frac{W_2 \times 1000}{M_2 \times W_1}$$

Thus,

$$m = \frac{41.67 \times 1000}{60 \times 50} = 14\text{m}$$

3. (a) Why is the freezing point depression considered as a colligative property?

Ans: The colligative properties depend upon the number of solute molecules in the solvent. The depression in freezing point is observed when the solute particles are introduced in the solution. Thus, it is one of the colligative properties.

(b) The cryoscopic constant of water is 1.86 k/m. Comment on this statement.

Ans: If it is said that the cryoscopic constant of water is 1.86Km^{-1}, it means that the water has 1.86 K depression in freezing point when the solution has molality of 1 m.

(c) Calculate the amount of ice that will separate out on cooling solution containing 50 g of ethylene glycol in 200 g H_2O to $-9.3°C$. (K_f for water = 1.86Kkgmol^{-1})

Ans: Given that,

$W_2 = 50g$

$M_2 = 62gmol^{-1}$

$K_f = 1.86Kkgmol^{-1}$

$\Delta T_f = 9.3°C$

Thus, using the formula for depression in freezing point,

$$\Delta T_f = \frac{K_f \times W_2 \times 1000}{W_1 \times M_2}$$

$$9.3 = \frac{1.86 \times 50 \times 1000}{W_1 \times 62}$$

$\therefore W_1 = 161.29g$

Therefore, ice separated = 200 – 161.29 = 38.71g.

4. (a) Define osmotic pressure.

Ans: The pressure that will prevent the process of osmosis is known as osmotic pressure. It is defined as the pressure applied at the side of pure solvent to prevent it to pass through semi – permeable membrane to the solution side by osmosis.

(b) Why osmotic pressure is preferred over other colligative properties for the determination of molecular masses of macromolecules?

Ans: The method of osmotic pressure takes into account the molarity of the solution unlike other methods who take molality as a multiplying factor. Also, the pressure measurement takes place at room temperature during osmosis.

(c) What is the molar concentration of particles in human blood if the osmotic pressure is 7.2 atm at normal body temperature of $37°C$?

Ans: Given that,

$\pi = 7.2 \text{atm}$

$R = 0.0821 \text{LatmK}^{-1} \text{mol}^{-1}$

$T = 37°C = 310K$

The osmotic pressure is given as;

$\pi = CRT$

The molar concentration is given as;

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

$$C = \frac{7.2}{0.082 \times 310} = 0.283M$$

NUMERICAL PROBLEMS

1. Calculate the mass percentage of benzene (C_6H_6) and carbon tetrachloride (CCl_4), If 22g of benzene is dissolved in 122g of carbon tetrachloride.

Ans: The mass percentage is given as;

$$\text{Mass percentage} = \frac{\text{mass of component}}{\text{mass of mixture}} \times 100$$

Here,

Mass of benzene = 22 g

Mass of carbon tetrachloride = 122 g

Mass of mixture = 22 + 122 = 144 g

Thus,

$$\text{Mass percentage of benzene} = \frac{\text{mass of benzene}}{\text{mass of mixture}} \times 100$$

$$=\frac{22}{144}\times 100=15.28\%$$

And,

$$\text{Mass percentage of } CCl_4 = \frac{\text{mass of } CCl_4}{\text{mass of mixture}}\times 100$$

$$=\frac{122}{144}\times 100=84.72\%$$

2. Calculate the molarity of a solution prepared by mixing 500 mL of 2.5 M urea solution and 500 mL of 2M urea solution.

Ans: Given that,

$M_1 = 2.5M$

$M_2 = 2M$

$V_1 = V_2 = 500ml$

Now, by the law of dilution, we get;

$$M=\frac{M_1V_1+M_2V_2}{V_1+V_2}$$

$$M=\frac{(2.5+2)\times 500}{1000}$$

Thus, molarity of the solution = 2.25 M.

3. The mole fraction of CH_3OH in an aqueous solution is 0.02 and density of solution 0.994 g/cm. Determine the molality and molarity.

Ans: Given that,

Molar mass of water = 18 g/mol

Molar mass of CH_3OH = 32 g/mol

$\text{Density} = 0.994 \text{gcm}^{-3}$

$$\text{Mole fraction of } CH_3OH = \frac{x}{x+y} = 0.02$$

where, x is the moles of CH_3OH and y is the moles of water in the solution.

By calculating, we get;

$y = 49x$

Now, molality is given as;

$$\text{Molality} = \frac{x \times 1000}{y \times 18} = 1.13\text{m}$$

Volume of the solution is given as,

$$\text{Volume} = \frac{\text{mass}}{\text{density}} = \frac{32x + 18y}{994}\text{L}$$

Hence, molarity is given as;

$$\text{Molarity} = \frac{x \times 994}{32x + 18y} = 1.0875\text{M}$$

4. 200 mL of calcium chloride solution contains $\mathbf{3.011 \times 10^{22} Cl^-}$ ions. Calculate the molarity of the solution. Assume that calcium chloride is completely ionized.

Ans: This illustration can be solved by simple mole concept;

We know that, $CaCl_2$ has 2 chloride ions. Thus,

The molecules of $CaCl_2$ will be

$$= \frac{3.01 \times 10^{22}}{2} \times \frac{1}{5\text{L}}$$

$= 7.525 \times 10^{22}$ molecules

Now, we have known that a mole of a substance contains 6.022×10^{23} molecules. Thus,

Molarity of solution is calculated as;

$$\text{Molarity} = \frac{7.525 \times 10^{22}}{6.022 \times 10^{23}} = 0.125\text{M}$$

5. 6×10^{-3} g oxygen is dissolved per kg of sea water. Calculate the ppm of oxygen in sea water.

Ans: Given that,

Mass of oxygen = 6×10^{-3}g

Mass of solution = 1 kg = 1000 g

Now,

ppm of oxygen in sea water is calculated as;

$$= \frac{\text{mass of solute}}{\text{mass of solution}} \times 10^{6}$$

$$= \frac{6 \times 10^{-3} \times 10^{6}}{1000} = 6\text{ppm}$$

6. The solubility of oxygen in water is 1.35×10^{-3} molL^{-1} at $20°C$ and 1 atm pressure. Calculate the concentration of oxygen at $20°C$ and 0.2 atm pressure.

Ans: Given that,

$C = 1.35 \times 10^{-3}$ molL^{-1}

P = 1 atm

We know the Henry's law;

$$C = K_H P$$

Thus,

$$K_H = \frac{C}{P} = 1.35 \times 10^{-3} \text{Matm}^{-1}$$

Now, at 0.2 atm;

$$C = 1.35 \times 10^{-3} \times 0.2$$

$$C = 2.7 \times 10^{-3} \text{M}$$

7. Two liquids X and Y on mixing form an ideal solution. The vapor pressure of the solution containing 2 mol of X and 1 mol of Y is 550 mm Hg. But when 4 mol of X and 1 mole of Y are mixed, the vapor pressure of solution thus formed is 560 mm Hg. What will be the vapor pressure of pure X and pure Y at this temperature?

Ans: Let us consider vapor pressure of X will be P_1 and that of Y will be P_2 . Also, x_1 and x_2 be their respective mole fractions.

Then by Raoult's law we can say that;

Total pressure, P

$$= P_1 x_1 + P_2 x_2$$

Thus,

For first solution;

$$P_1 \times \left(\frac{2}{2+1} \right) + P_2 \times \left(\frac{1}{2+1} \right) = 550 \ldots\ldots$$

For second solution;

$$P_1 \times \left(\frac{4}{4+1} \right) + P_2 \times \left(\frac{1}{4+1} \right) = 560 \ldots\ldots$$

Now, both the equations we get,

Vapor pressure of pure component X,

$P_1 = 575 mmHg$

Vapor pressure of pure component Y,

$P_2 = 500 mmHg$

8. An aqueous solution containing 3.12 g of barium chloride in 250 g of water is found to be boil at $100.0832°C$. Calculate the degree of dissociation of barium chloride.

[Given molar mass $BaCl_2$ = $208 gmol^{-1}$, K_b for water = 0.52 K/m]

Ans: Given that,

$M_2 = 208 gmol^{-1}$

$K_b = 0.52 Kkgmol^{-1}$

$\Delta T_b = 100.0832 - 100 = 0.0832 K$

$W_2 = 3.12 g$

$W_1 = 250 g$

By formula we get;

$\Delta T_b = iK_b m$

The Van’t Hoff factor is given as;

$$i = \frac{\Delta T_b}{K_b m} = \frac{\Delta T_b \times M_2 \times W_1}{K_b \times W_2 \times 1000} = 2.67$$

Also, we know that i = moles at equilibrium. Thus,

$$\underset{1-x}{BaCl_2} \rightleftarrows \underset{x}{Ba^{2+}} + \underset{2x}{2Cl^-}$$

Solving this we get;

$i = 1 - x + x + 2x = 2.67$

Therefore, degree of dissociation is 83.5%.

9. The degree of dissociation of $Ca(NO_3)_2$ in a dilute aqueous solution, containing 7.0 g of salt per 100 g of water at 100°C is 70%. If the vapor pressure of water at 100°C is 760 mm of Hg, calculate the vapor pressure of the solution.

Ans: Given that,

Degree of dissociation, α = 70%

$W_2 = 7g$

$M_2 = 164 gmol^{-1}$

$W_1 = 100g$

$M_1 = 18 gmol^{-1}$

$P^0 = 760 mmHg$

Moles of $Ca(NO_3)_2$

$$= \frac{7}{164} = 0.0426 moles$$

Moles of water

$$= \frac{100}{18} = 5.56 moles$$

Mole fraction of $Ca(NO_3)_2$, X

$$= \frac{0.0426}{0.0426 + 5.56} = 0.00762$$

Number of ions of $Ca(NO_3)_2$ on dissociation, $n' = 3$

The Van't Hoff factor is given as;

$$i = [1 + (n' - 1)\alpha]$$

Thus, i = 2.4

Now,

The relative lowering of vapor pressure is given as;

$$\frac{P^0 - P}{P^0} = iX$$

$$\frac{760 - P}{760} = 2.4 \times 0.00762$$

Thus, the vapor pressure of the solution, P = 746.1 mm Hg.

10. 2g of C_6H_5COOH dissolved in 25g of benzene shows depression in freezing point equal to 1.62K. Molar freezing point depression constant for benzene is $4.9 K kg mol^{-1}$. What is the percentage association of acid if it forms a dimer in solution?

Ans: Given that,

$W_2 = 2g$

$W_1 = 25g$

$K_f = 4.9 K kg mol^{-1}$

$\Delta T_f = 1.62K$

Normal molar mass of C_6H_5COOH = 122 g/mol

Calculated molar mass of C_6H_5COOH is given as;

$$M_2 = \frac{K_f \times W_2 \times 1000}{\Delta T_f \times W_1} = 241.98\text{gmol}^{-1}$$

The Van't Hoff factor is given as;

$$i = \frac{\text{normal molar mass}}{\text{calc. molar mass}} = \frac{122}{241.98}$$

Also,

$$\underset{1-x}{2C_6H_5COOH} \rightleftarrows \underset{x/2}{(C_6H_5COOH)_2}$$

Hence,

$$i = 1 - x + \frac{x}{2} = 1 - \frac{x}{2} = \frac{122}{241.98}$$

Therefore, degree of association is 99.2%.

11. Calculate the amount of NaCl which must added to one kg of water so that the freezing point is depressed by 3K. Given K_f = 1.86Kkgmol^{-1} , Atomic mass: Na = 23, Cl = 35.5).

Ans: Given that,

$$W_1 = 1\text{kg}$$

$$K_f = 1.86\text{Kkgmol}^{-1}$$

$$\Delta T_f = 3\text{K}$$

$$M_2 = 58.5\text{gmol}^{-1}$$

NaCl can dissociate giving 2 ions. Thus, i = 2.

Therefore, by formula;

$$W_2 = \frac{\Delta T_f \times M_2 \times W_1}{i \times K_f} = 47.2\text{g}$$

Moles of NaCl

$$=\frac{47.2}{58.5}=0.81\text{mol}$$

12. Three molecules of a solute (A) associate in benzene to form species A_3 .

Calculate the freezing point of 0.25 molal solution. The degree of association of solute A is found to be 0.8. The freezing point of benzene is $5.5°C$ and its K_f value is 5.13 K/m.

Ans: Given that,

3 (n') molecules of a solute (A) associate in benzene to form species A_3 .

Molality = 0.25 m

Degree of association, α = 0.8

$$T_{benzene}=5.5°C$$

$$K_f=5.13\text{Km}^{-1}$$

Now,

$$\underset{1-\alpha}{3A}\rightleftarrows\underset{\alpha/3}{A_3}$$

$$i=1-\alpha+\frac{\alpha}{3}=1-\frac{2\alpha}{3}$$

Van't Hoff factor, i = 0.467

The depression in freezing point is given as;

$$\Delta T_f=iK_fm$$

$$\Delta T_f=0.467\times 5.13\times 0.25=0.5985°C$$

The freezing point of the solution is given as;

$$T=T_{benzene}-\Delta T_f$$

Thus, T = 5.5 – 0.5985 = $4.90°C$.

13. A 5% solution of sucrose ($C_{12}H_{22}O_{11}$) is isotonic with 0.877% solution of urea (NH_2CONH_2) Calculate the molecular mass of urea.

Ans: Given that,

Mass of sucrose = 5 g

Mass of urea = 0.877 g

In general, when two solutions are isotonic with each other means they have equal osmotic pressure and due its directly proportionality with the concentrations, isotonic solutions have equal concentrations. Thus,

Conc. Of sucrose = Conc. Of urea

$$\frac{\text{mass of sucrose}}{\text{molar mass of sucrose}} = \frac{\text{mass of urea}}{\text{molar mass of urea}}$$

We know the molar mass of sucrose as 342 g/mol. Thus, molar mass of urea is calculated as;

$$= \frac{0.877 \times 342}{5} = 59.9\text{gmol}^{-1}$$

14. Osmotic pressure of a 0.0103 molar solution of an electrolyte was found to be 0.75 atm at $27°C$. Calculate Van't Hoff factor.

Ans: Given that,

$\pi = 0.75\text{atm}$

$C = 0.0103\text{m}$

$R = 0.0820\text{Latmmol}^{-1}\text{K}^{-1}$

$T = 27°C = 300K$

By the formula of osmotic pressure, we get;

$$\pi = iCRT$$

$$\therefore i = \frac{\pi}{CRT} = \frac{0.75}{0.0103 \times 0.082 \times 300} = 2.95$$

15. The maximum allowable level of nitrates in drinking water is 45 mg nitrate ionsdm^{-3} . Express this level in ppm?

Ans: Given that,

The maximum allowable level of nitrates in drinking water =
45 mg nitrates ions dm^{-3} = 45 mgL^{-1} .

We know that, $1mgL^{-1} = 1ppm$. Thus,

The maximum allowable level of nitrates in drinking water = 45 ppm.

16. 75.2 g of Phenol (C_6H_5OH) is dissolved in 1 kg solvent of $K_f = 14Km^{-1}$, if the depression in freezing point is 7K, then find the % of phenol that dimerises.

Ans: Given that,

$W_2 = 75.2g$

$M_2 = 94gmol^{-1}$

$\Delta T_f = 7K$

$K_f = 14Km^{-1}$

$W_1 = 1kg$

And,

$$\underset{1-\alpha}{2C_6H_5OH} \rightleftarrows \underset{\alpha/2}{(C_6H_5OH)_2}$$

Thus,

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

Now, by formula;

$$\Delta T_f = iK_f m$$

$$\alpha = 2 \times \left(1 - \frac{\Delta T_f \times M_2 \times W_1}{K_f \times W_2 \times 1000}\right)$$

$$\alpha = 0.75$$

% Phenol which will dimerise is 75%.

17. An aqueous solution of glucose boils at $100.01°C$. The molal boiling point elevation constant for water is $0.5 K kg mol^{-1}$. What is the number of glucose molecules in the solution containing 100 g of water?

Ans: Given that,

$$W_1 = 100g$$

$$K_b = 0.5 K kg mol^{-1}$$

$$\Delta T_b = 100.01 - 100 = 0.01 K$$

$$M_2 = 180 g mol^{-1}$$

By using the formula of elevation in boiling point;

$$\Delta T_b = K_b \frac{n_2}{W_1}$$

$$\therefore n_2 = \frac{0.01 \times 0.1}{0.5} = 2 \times 10^3 moles$$

From mole concept;

Number of glucose molecules, $N_a = n_2 \times 6.022 \times 10^{23} = 12.046 \times 10^{20}$ molecules .

18. A bottle of commercial H_2SO_4 [density = 1.787 g/mL] is labelled as 86% by mass.

(a) What is the molarity of the acid?

Ans: Given that,

Mass of acid = 86 g

Molar mass of acid = 98 g/mol

Mass of solution = 100 g

Density = 1.787 g/ml

Thus, volume is given as;

$$\text{Volume} = \frac{\text{mass}}{\text{density}} = \frac{100}{1.787} = 56\text{ml}$$

Thus, molarity is given as;

$$M = \frac{86 \times 1000}{98 \times 56} = 15.71M$$

(b) What volume of the acid has to be used to make 1 liter 0.2M H_2SO_4?

Ans: Given that,

$M_2 = 0.2M$

$V_2 = 1L$

From above question,

$M_1 = 15.71M$

By formula we can state that;

$$M_1V_1 = M_2V_2$$

$$V_1 = \frac{M_2V_2}{M_1} = 0.0127L$$

(c) What is the molality of the acid?

Ans: Mass of solvent = 100 – 86 = 14 g.

Molality can be given as;

$$\text{Molality} = \frac{86 \times 1000}{98 \times 14} = 62.68\text{m}$$

19. A solution containing 30g of non-volatile solute exactly in 90g of water has a vapor pressure of 2.8 kPa at 298 K. Further, 18 g of water is then added to the solution and the new vapor pressure becomes 2.9 kPa at 298 K. Calculate:

(i) molar mass of the solute

Ans: Given that,

$$W_2 = 30\text{g}$$

$$W_1 = 90\text{g}$$

$$P_S = 2.8\text{kPa}$$

Now, according to Raoult's law;

$$\frac{P^0 - P_S}{P^0} = x \approx \frac{W_2M_1}{M_2W_1}$$

$$1 - \frac{6}{M_2} = \frac{2.8}{P^0}$$

After adding water,

$$W_2 = 30\text{g}$$

$W_1 = 90 + 18 = 108\text{g}$

$P_S = 2.9\text{kPa}$

Now, according to Raoult's law;

$$\frac{P^0 - P_S}{P^0} = x \approx \frac{W_2 M_1}{M_2 W_1}$$

$$1 - \frac{5}{M_2} = \frac{2.9}{P^0}$$

Now taking into account both the equations;

$M_2 = 34\text{gmol}^{-1}$

(ii) Vapor pressure of water at 298 K.

Ans: Now, substituting the value of molar mass in one of the equation;

$$1 - \frac{6}{34} = \frac{2.8}{P^0}$$

Thus, $P^0 = 3.4\text{kPa}$.

20. The vapor pressure of pure liquids A and B are 450- and 750-mm Hg respectively, at 350K. Find out the composition of the liquid mixture if total vapor pressure is 600 mm Hg. Also find the composition of the vapor phase.

Ans: Given that,

$P_A^0 = 450\text{mmHg}$

$P_B^0 = 750\text{mmHg}$

$P_T = 600\text{mmHg}$

Now, from Raoult's law;

$P_A = P_A^0 x_A$

$P_B = P_B^0 x_B = P_B^0 (1 - x_A)$

So,

$P_T = P_A + P_B$

Now,

$P_T = P_A^0 x_A + P_B^0 (1 - x_A)$

$$x_A = \frac{P_T - P_B^0}{P_A^0 - P_B^0}$$

From this,

$x_A = 0.5$

$x_B = 0.5$

This gives us;

$P_A = 450 \times 0.5 = 225 \text{mmHg}$

$P_B = 750 \times 0.5 = 375 \text{mmHg}$

Now,

Composition in vapor phase is given as;

$$y_A = \frac{P_A}{P_T} = \frac{225}{600} = 0.375$$

$y_A = 1 - y_A = 1 - 0.375 = 0.625$

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

Ans: Given that,

$P_S = 1.004 \text{bar}$

$W_2 = 2g$

Mass of solution = 100g

$W_1 = 100 - 2 = 98g$

$M_1 = 18 g mol^{-1}$

We know that VP of pure water, $P^0 = 1 atm = 1.013 bar$

By Raoult's law;

$$\frac{1.013 - 1.004}{1.013} = \frac{2 \times 18}{M_2 \times 98}$$

Thus, molar mass of the solute, $M_2 = 41.35 g mol^{-1}$.