

## Chapter 2

### Solutions

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#### 1 Marks Questions

**1. Define the term –solubility?**

**Ans.** The maximum amount of a substance that can be dissolved in a specified amount of solvent is called its solubility.

**2. What is the effect of pressure on solubility of a gas?**

**Ans.** The solubility of a gas increases with increases of pressure.

**3. State Henry's Law.**

**Ans.** Henry's Law states that at a constant temperature the solubility of a gas in a liquid is directly proportional to the pressure of the gas.

**4. State Raoult's Law.**

**Ans.** Raoult's Law states that for a solution of volatile liquids, the partial vapour pressure of each component in the solution is directly proportional to its mole fraction.

**5. What are the factors on which vapour pressure depends?**

**Ans.** The factors on which vapour pressure depends are –

1) Temperature of the liquid.      2) Nature of the liquid.

**6. The vapour pressure of solvent gets lowered, when a non- volatile solute is**

**added to it. Why?**

**Ans.** When a non-volatile solute is added to a solvent, the surface area for escape of solvent molecules decreases and vapour pressure gets lowered.



**7. Name two ways by which vapour pressure of a liquid can be lowered.**

**Ans.** The two ways by which vapour pressure can be lowered are –

- 1) By decreasing the temperature.
- 2) By adding a non-volatile solute.

**8. Define 'solution'?**

**Ans.** Solutions are homogeneous mixtures of two or more than two components.

**9. Define the following terms : (a) Molality (b) Molarity**

**Ans.** (a) Molality is defined as the number of moles of the solute per kilogram of solvent.

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

(b) Molarity (M) = Number of moles of solute dissolved in one litre of solution.

$$\text{Molarity (M)} = \frac{\text{No. of Moles of solute}}{\text{Volume of solution in litre}} \text{ Molarity (M)}$$

**10. How does change in temperature changes the molarity and molality values?**

**Ans.** As the temperature increases, volume increases and molarity decreases whereas molality does not change with any change in temperature.

**11. Define the term colligative properties?**

**Ans.** The properties which depends upon amount of solute and not upon the nature of solute are called colligative properties.

**12. What are the possible deviations from ideal behaviors?**

**Ans.** There are two types of deviation from ideal behaviour – positive and negative deviations.

**13. Give one example of each deviation?**

**Ans.** Positive deviation – ethanol and acetone.

Negative deviation – chloroform and acetone.

**14.** At  $400^{\circ}\text{C}$ , the vapour pressure of water is 55.3 mm Hg .Calculate the vapour pressure at the same temperature over 10% aqueous solution of urea  $[\text{CO}(\text{NH}_2)_2]$ ?

**Ans.** 53.48 mm Hg.

**15.** How much urea (molar mass 60 g/mol) should be dissolved in 50g of water so that its vapour pressure at room temperature is reduced by 25%?

**Ans.** 41.7 g .

**16.** Why is the boiling point elevated when a non – volatile solute is dissolved in a liquid?

**Ans.** When a non – volatile solute is added the vapour pressure decreases and the solution is heated to a higher temperature, increasing the boiling point.

**17.** How is boiling point changed when mass of solvent is doubled?

**Ans.** 
$$\Delta T_b = K_b \frac{W_{\text{solute}}}{W_{\text{solvent}}} \times \frac{1000}{M_{\text{solute}}}$$

= when the amount of solvent is doubled,  $\Delta T_b$  is halved.

**18.** What happens when red blood cells are placed in 0.1% NaCl solution?

**Ans.** Water from NaCl solution passes into cells & they swell. Finally they will burst.

**19.** How is osmotic pressure of a solution related to its concentration?

**Ans.** Osmotic pressure,  $\pi = CRT$

C = concentration ,R = gas constant.

T= temperature

**20.** Calculate the osmotic pressure of 0.25 M solution of urea at  $37^{\circ}\text{C}$ . R = 0.083 L



bar/mol.k.

Ans.  $T = 37^{\circ}C = 310k$

$$T_1 = CRT = \frac{n}{v} RT$$

$$= 0.25 \times 0.083 \times 310 = 6.43 \text{ bar.}$$

21. An aqueous solution of glucose,  $C_6H_{12}O_6$  has osmotic pressure of 2.72 atm at 298k. How many moles of glucose were dissolved per litre of solution?

Ans. 0.111 mol.

22. When does the measurement of colligative property leads to abnormal molecular mass?

Ans. When the solute undergoes either association or disassociation abnormal molar mass is obtained.

23. When is the value of  $i$  less than unity?

Ans. When the solute undergoes association in solution,  $i$  is less than unity.

24. The molecular mass of a solute is 120 g/mol and van't Hoff factor is 4. What is its abnormal molecular mass?

Ans. Abnormal molecular mass =  $\frac{\text{Normal molecular mass}}{i}$

$$= \frac{120}{4} = 30 \text{ g/mol.}$$



## 2 Marks Questions

1. Calculate the volume of water which could be added to 20 ml of 0.65 M HCl to dilute the solution to 0.2 M?

Ans. For dilution –

$$M_1V_1 = M_2V_2$$

$$V_2 = \frac{M_1V_1}{M_2} = \frac{0.65M \times 20 \text{ ml}}{0.2M} = 65 \text{ ml}$$

Vol of water to be added to 20 ml =  $V_2 - V_1 = 65\text{ml} - 20\text{ml} = 45 \text{ ml}$ .

2. A solution is prepared by dissolving 11g glucose in  $200 \text{ cm}^3$  water at  $30^\circ \text{C}$ . What is the mass Percentage of glucose in solution? The density of water

$30^\circ \text{C}$  is  $0.996 \text{ g/cm}^3$ ?

$$\text{Ans. Density} = \frac{\text{mass}}{\text{volume}} = 0.996 \text{ g/cm}^3$$

$$0.996 = \frac{\text{mass}}{200\text{cm}^3}$$

$$\text{Mass} = 0.996 \times 200 = 199.2 \text{ g}$$

$$\text{Mass\% of glucose} = \frac{\text{mass of glucose}}{\text{mass of water} + \text{mass of glucose}} \times 100$$

$$= \frac{11}{199.2 + 11} \times 100 = 5.23 \%$$

3. Carbon tetrachloride and water are immiscible whereas alcohol and water are miscible. Explain on the basis of molecular structures of these compounds.

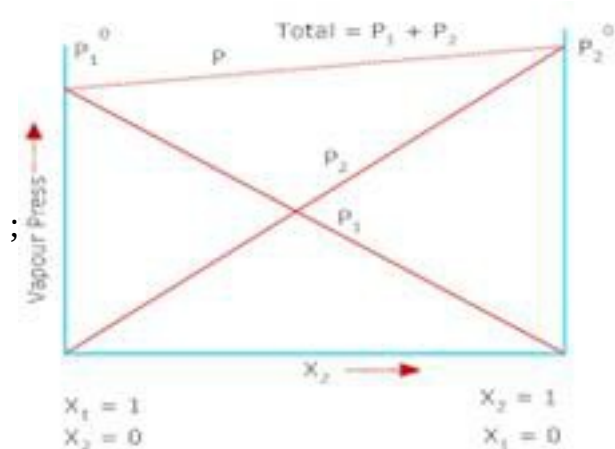
Ans. Carbon tetrachloride is a non-polar compound whereas water is a polar compound. They do not interact with each other and carbon tetrachloride cannot dissolve in water whereas alcohol and water are completely miscible due to high polarity.

4. Why do mountaineers carry oxygen cylinder while climbing mountains?

Ans. At high altitudes the partial pressure of oxygen is less than that of the ground level which decreases the concentration of oxygen in blood and tissues. Low blood oxygen causes climbers to become weak and unable to think clearly & they suffer from anoxia. To avoid such situations, mountaineers carry oxygen cylinder while climbing.

5. Plot a graph between vapour pressure and mole fraction of a solution obeying Raoult's Law at constant temperature?

Ans.



6. Name different colligative properties?

Ans. The colligative properties are –

- Relative lowering of vapour pressure.
- Elevation in boiling point.
- Depression in freezing point
- Osmotic pressure.

7. Give the characteristics of ideal solution?

Ans. An ideal solution is formed from two liquids only when –

- They obey Raoult's Law
- $\Delta H_{\text{mix}} = 0$
- $\Delta V_{\text{mix}} = 0$

d) The various inter molecular forces are identical.

8. A mixture of chlorobenzene and bromobenzene is a nearly an ideal solution but a mixture of chloroform and acetone is not Explain?

Ans. Chlorobenzene & bromobenzene both have similar structure and polarity. Therefore the various interactions (solute – solute, solvent – solvent & solute – solvent) are same whereas in chloroform and acetone initially there is no hydrogen bonding but after mixing solute solvent interactions (H –bond ) become stronger and solution deviates from ideal behaviour.

9. 0.90g of a non – electrolyte was dissolved in 87.90g of benzene. This raised the boiling point of benzene by  $0.25^{\circ}C$ . If the molecular mass of non – electrolyte is 103.0 g/mol, calculate the molal elevation constant for benzene?

$$\text{Ans. } \Delta T_b = K_b \frac{W_{\text{solute}}}{W_{\text{solvent}}} \times \frac{1000}{M_{\text{solute}}}$$

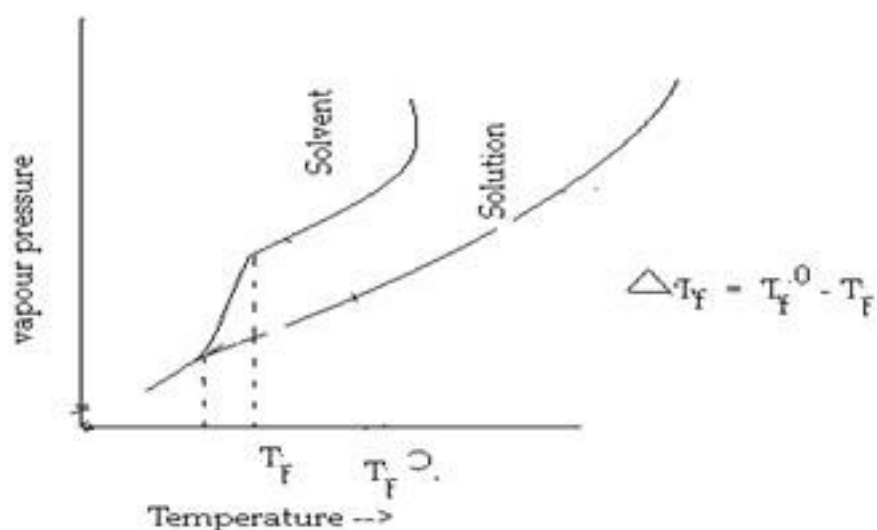
$$K_b = \Delta T_b \times M_{\text{solute}} \times \frac{W_{\text{solvent}}}{W_{\text{solute}}} \times \frac{1}{1000}$$

$$= 103 \times 0.25 \times \frac{87.90}{0.90} \times \frac{1}{1000}$$

$$= 2.514 \text{ k kg/mol.}$$

10. Show graphically the depression in freezing point on adding a non volatile solute?

Ans.



11. Define cryoscopic constant?

Ans. When 1 mole of a solute (that neither dissociates nor associates) is dissolved in 1kg of solvent, the depression in freezing point is called cryoscopic constant.

12. When 20g of a non – volatile solid is added to 250 ml of water, the freezing point of water becomes  $-0.9^{\circ}C$ . Calculate molecular mass of the solid if  $k_f$  of water is  $1.86^{\circ}Ckg/mol$ .

Ans. 250 ml = 250g as density of water = 1g/ml

Freezing pt of water = 273k

Freezing point of solution =  $-0.90C + 273 = 272.1k$

$\Delta T_f = 273 k - 272.1k = 0.9k$

$$M_{\text{solute}} = \frac{K_f \times W_{\text{solute}} \times 1000}{\Delta T_f \times W_{\text{solvent}}}$$
$$= \frac{1.86 \times 26 \times 1000}{0.9 \times 250} = 165.3 \text{ g/mol.}$$

13. Give various expressions for van't Hoff factor?

$$\text{Ans. } i = \frac{\text{Normal Molar mass}}{\text{Abnormal molar mass}}$$

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

$$= \frac{\text{Total no. of moles of particles after association/dissociation}}{\text{Total no. of moles of particles before association/dissociation}}$$





14. How are the various colligative properties modified after consideration of van't Hoff factor?

Ans. a)  $\frac{p_1^0 - p_1}{p_1^0} = i X_2$

b)  $\Delta T_b = i K_b m$

c)  $\Delta T_f = i K_f m$

d)  $\pi = i CRT$

15. The boiling point elevation of 0.6 g acetic acid in 100g benzene is 0.1265k. What conclusion can you draw about the state of solute in solution? Molar elevation constant for benzene is 2.53 deg per molar?

Ans. Molality of acetic acid =  $\frac{0.6}{60} \times \frac{1000}{100}$

= 0.10 m.

$$\Delta T_b = K_b \times m$$

$$M = \frac{\Delta T_b}{K_b} = \frac{0.1265}{2.53} = 0.050 \text{ m}$$

$$i = \frac{0.050}{0.10} = 0.50$$

Since  $i = \frac{1}{2}$ , acetic acid exist as dimer in solution.

16. The osmotic pressure of a 0.0103 molar solution of an electrolyte is found to be 0.70 atm at  $273^{\circ}C$ . Calculate van't Hoff factor.  $R=0.082 \text{ L atm/1 mol/k}$ ?

Ans.  $i = 2.76$  The solute is dissociated in solution.

17. Calculate the mass percentage of aspirin ( $C_9H_8O_4$ ) in acetonitrile ( $CH_3CN$ ) when 6.5 g of  $C_9H_8O_4$  is dissolved in 450 g of  $CH_3CN$ .

Ans. 6.5 g of  $C_9H_8O_4$  is dissolved in 450 g of  $CH_3CN$ .

Then, total mass of the solution = (6.5 + 450) g

= 456.5 g

Therefore, mass percentage of  $C_9H_8O_4 = \frac{6.5}{456.5} \times 100\%$

= 1.424%

18. If the density of some lake water is  $1.25 \text{ g ml}^{-1}$  and contains 92 g of  $Na^+$  ions per kg of water, calculate the molality of  $Na^+$  ions in the lake.

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

= 4 mol

Therefore, molality of  $Na^+$  ions in the lake  $\frac{4 \text{ mol}}{1 \text{ kg}}$

= 4 m

19. At 300 K, 36 g of glucose present in a litre of its solution has an osmotic pressure of 4.98

bar. If the osmotic pressure of the solution is 1.52 bars at the same temperature, what would be its concentration?

Ans. Here,

$$T = 300 \text{ K}$$

$$\pi = 1.52 \text{ bar}$$

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

Applying the relation,

$$\pi = CRT$$

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

$$= \frac{1.52 \text{ bar}}{0.083 \text{ bar L K}^{-1} \text{ mol}^{-1} \times 300 \text{ K}}$$

$$= 0.061 \text{ mol}$$

Since the volume of the solution is 1 L, the concentration of the solution would be 0.061 M.

20. Suggest the most important type of intermolecular attractive interaction in the following pairs.

(i) n-hexane and n-octane

(ii)  $\text{I}_2$  and  $\text{CCl}_4$

(iii)  $\text{NaClO}_4$  and water

(iv) methanol and acetone

(v) acetonitrile  $\text{CH}_3\text{CN}$  and acetone ( $\text{C}_3\text{H}_6\text{O}$ ).

Ans. (i) Van der Waals forces of attraction.



(ii) Van der Waals forces of attraction.

(iii) Ion-dipole interaction.

(iv) Dipole-dipole interaction.

(v) Dipole-dipole interaction.

21. Based on solute-solvent interactions, arrange the following in order of increasing solubility in *n*-octane and explain. Cyclohexane, KCl,  $\text{CH}_3\text{OH}$ ,  $\text{CH}_3\text{CN}$ .

Ans. *n*-octane is a non-polar solvent. Therefore, the solubility of a non-polar solute is more than that of a polar solute in the *n*-octane.

The order of increasing polarity is:

Cyclohexane <  $\text{CH}_3\text{CN}$  <  $\text{CH}_3\text{OH}$  < KCl

Therefore, the order of increasing solubility is:

KCl <  $\text{CH}_3\text{OH}$  <  $\text{CH}_3\text{CN}$  < Cyclohexane

22. A sample of drinking water was found to be severely contaminated with chloroform ( $\text{CHCl}_3$ ) supposed to be a carcinogen. The level of contamination was 15 ppm (by mass):

(i) express this in percent by mass

(ii) determine the molality of chloroform in the water sample.

Ans. (i) 15 ppm (by mass) means 15 parts per million (10<sup>6</sup>) of the solution.

Therefore, percent by mass =  $\frac{15}{10^6} \times 100\%$

=  $1.5 \times 10^{-3}\%$

(ii) Molar mass of chloroform ( $\text{CHCl}_3$ ) =  $1 \times 12 + 1 \times 1 + 3 \times 35.5$

=  $119.5 \text{ g mol}^{-1}$

Now, according to the question,

15 g of chloroform is present in 106 g of the solution.

i.e., 15 g of chloroform is present in  $(106 - 15) = 91$  g of water.

$$\text{Therefore, Molality of the solution} = \frac{15}{119.5} \text{ mol} \\ \frac{10^6 \times 10^{-3} \text{ Kg}}$$

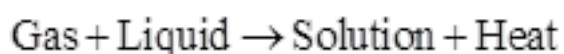
$$= 1.26 \times 10^{-4} \text{ m}$$

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

Ans. In pure alcohol and water, the molecules are held tightly by a strong hydrogen bonding. The interaction between the molecules of alcohol and water is weaker than alcohol-alcohol and water-water interactions. As a result, when alcohol and water are mixed, the intermolecular interactions become weaker and the molecules can easily escape. This increases the vapour pressure of the solution, which in turn lowers the boiling point of the resulting solution.

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

Ans. Solubility of gases in liquids decreases with an increase in temperature. This is because dissolution of gases in liquids is an exothermic process.



Therefore, when the temperature is increased, heat is supplied and the equilibrium shifts backwards, thereby decreasing the solubility of gases.

25. Give an example of solid solution in which the solute is a gas.

Ans. In case a solid solution is formed between two substances (one having very large particles and the other having very small particles), an interstitial solid solution will be formed. For example, a solution of hydrogen in palladium is a solid solution in which the solute is a gas.

### 3 Marks Questions

1. Find the molality and molarity of a 15% solution of  $H_2SO_4$  when its density is  $1.10 \text{ g/cm}^3$  & molar mass = 98 amu.

Ans. Volume = mass/density

$$= 100 \text{ g} / 1.10 \text{ g/cm}^3 = 90.9 \text{ cm}^3$$

$$\text{Molarity} = \frac{\text{no. of moles of } H_2SO_4}{\text{volume of solution}} \times 1000$$

$$= \frac{(15/98)}{90.9} \times 1000 = 1.68 \text{ m.}$$

$$\text{Molality} = \frac{\text{no. of moles of solute}}{\text{mass of solvent in kg}}$$

$$\frac{(15/98)}{85 \text{ g}} \times 1000 = 1.8 \text{ M.}$$

2. Calculate the mole fraction of ethanol and water in a sample of rectified spirit which contains 46% ethanol by mass?

Ans. Mass of ethanol = 46g

Mass of water =  $100 - 46 = 54\text{g}$

$$\text{Mole fraction of ethanol, } X_A = \frac{X_A}{X_A + X_B}$$

$$= \frac{\frac{46}{46}}{\frac{46}{46} + \frac{54}{18}} = \frac{1}{1+3} = \frac{1}{4} = 0.25.$$

Mole fraction of water =  $1 - 0.25 = 0.75$



3. Calculate the % composition in terms of mass of a solution obtained by mixing 300g of a 25% & 400 g of a 40% solution by mass?

$$\text{Ans. mass of solute in 400g of 40\%} = \frac{40}{100} \times 400 = 160\text{g}$$

$$\text{Total mass of solute} = 160 + 75 = 235\text{g}$$

$$\text{Total mass of solution} = 400 + 300 = 700\text{g}$$

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

$$= \frac{235}{700} \times 100 = 33.57\%$$

$$\text{Mass \% of solvent} = 100 - 33.57 = 66.43\%$$

4. One litre of sea water weight 1030g and contains about  $6 \times 10^{-3}$  g of dissolved  $O_2$ . Calculate the concentration of dissolved oxygen in ppm?

$$\text{Ans. mass of } O_2 = 6 \times 10^{-3} \text{ g}$$

$$\text{ppm of } O_2 \text{ in 1030 g sea water} = \frac{\text{mass of } O_2}{\text{mass of sea water}} \times 10^6 = \frac{6 \times 10^{-3}}{1030} \times 10^6 = 5.8 \text{ ppm.}$$

5. The density of 85% phosphoric acid is  $1.70 \text{ g/cm}^3$ . What is the volume of a solution that contains 17g of phosphoric acid?

Ans. 85g phosphoric acid is present in 100g of solution.

$$17\text{g of phosphoric acid is present in } \frac{100}{85} \times 17 = 20\text{g of solution}$$

$$\text{Volume of 17g of 85\% acid} = \frac{\text{mass}}{\text{density}}$$

$$= \frac{20\text{g}}{1.70 \text{ g/cm}^3} = 11.8 \text{ cm}^3$$



6. Define the term azeotrope?

Ans. A solution at certain concentration when continues to boil at constant temperature without change in its composition in solution & in vapour phase is called an azeotrope.

7. Obtain a relationship between relative lowering of vapour pressure and mole fraction of solute?

Ans. According to Raoult's Law –

$$P_1 = x_1 p_1^0$$

$$\Delta P = P_1^0 - P = P_1^0 - P_1^0 X_1$$

$$= \Delta P_1 = P_1^0 (1 - X_1)$$

$$\Delta P_1 = P_1^0 X_2 \quad (X_1 + X_2 = 1)$$

$$\frac{\Delta P_1}{P_1^0} = X_2$$

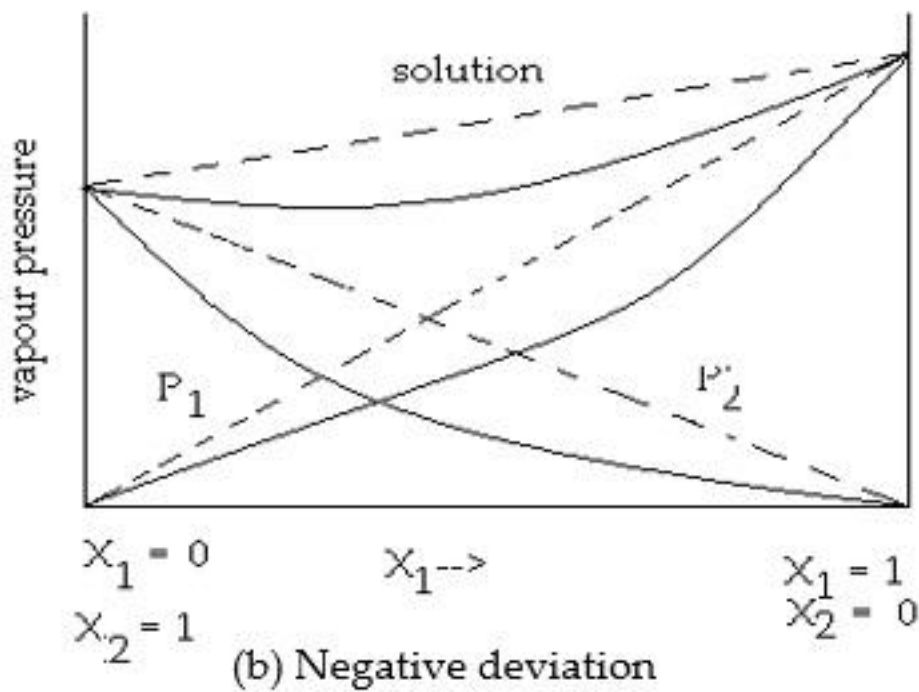
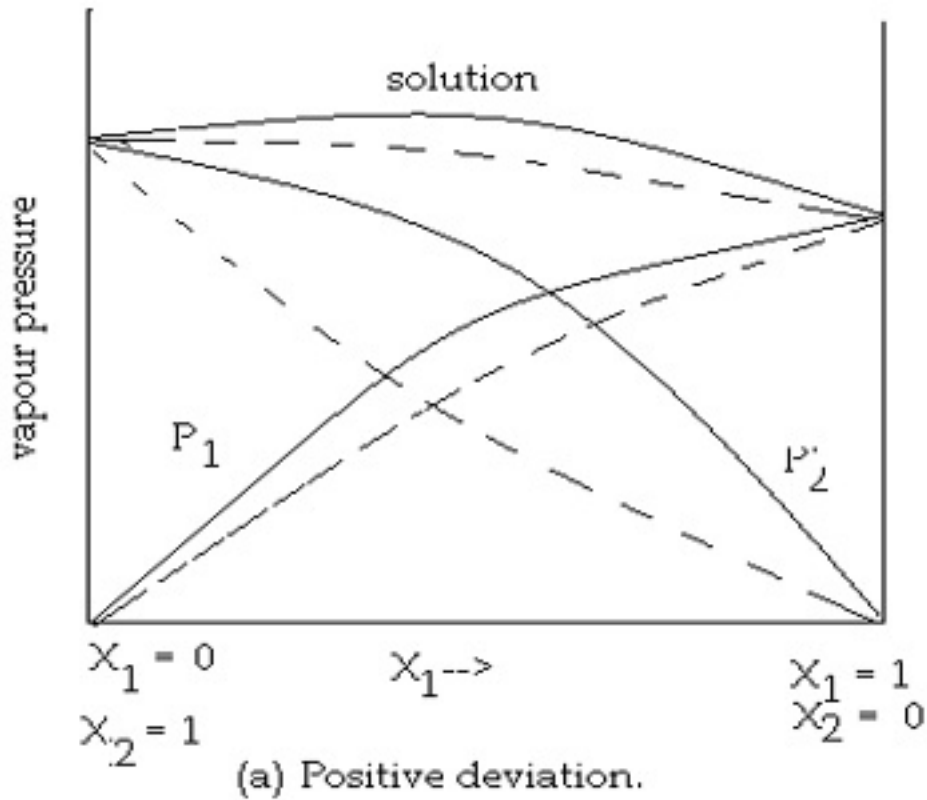
$$= \frac{P_1^0 - P_1}{P_1^0} = X_2$$

Relative lowering of vapour pressure.



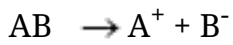
8. Draw the graphs of both deviations from ideal behaviours?

Ans.



9. A weak electrolyte AB is 5% dissociated in aqueous solution? What is the freezing point of a 0.10 molar aqueous solution of AB?  $K_f = 1.86 \text{ deg/molal}$ ?

Ans. Degree of dissociation  $\alpha$  of AB =  $\frac{5}{100} = 0.05$ .



$$M \quad 0 \quad 0$$

No. of moles dissolved

$$\text{No. of moles after dissociations } m(1-\alpha) \quad m\alpha \quad m\alpha$$

$$0.1(1-0.05) \quad 0.1 \times 0.05 \quad 0.1 \times 0.05$$

$$\text{Total moles} = [0.1(1-0.05)] + (0.1 \times 0.05) + (0.1 \times 0.05)$$

$$= 0.095 + 0.005 + 0.005 = 0.105m$$

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

$$= 1.86 \times 0.105$$

$$= 0.1953 \text{ deg.}$$

$$T_f = 0^\circ C - 0.1953 = -0.1953^\circ C$$

10. Henry's law constant for the molality of methane in benzene at 298 K is  $4.27 \times 10^5 \text{ mm Hg}$ . Calculate the solubility of methane in benzene at 298 K under 760 mm Hg.

Ans. Here,

$$p = 760 \text{ mm Hg}$$



$$k_H = 4.27 \times 10^5 \text{ mm Hg}$$

According to Henry's law,

$$p = k_H x$$

$$x = \frac{p}{k_H}$$

$$= \frac{760 \text{ mm Hg}}{4.27 \times 10^5 \text{ mm Hg}}$$

$$= 177.99 \times 10^{-5}$$

$$= 178 \times 10^{-5} \text{ (approximately)}$$

Hence, the mole fraction of methane in benzene is  $178 \times 10^{-5}$ .

11. Nalorphene  $C_{19}H_{21}NO_3$ , similar to morphine, is used to combat withdrawal symptoms in narcotic users. Dose of nalorphene generally given is 1.5 mg. Calculate the mass of  $1.5 \times 10^{-3} \text{ m}$  aqueous solution required for the above dose.

Ans. The molar mass of nalorphene  $C_{19}H_{21}NO_3$  is given as:

$$19 \times 12 + 21 \times 1 + 1 \times 14 + 3 \times 16 = 311 \text{ g mol}^{-1}$$

In  $1.5 \times 10^{-3} \text{ m}$  aqueous solution of nalorphene,

$$1 \text{ kg (1000 g) of water contains } 1.5 \times 10^{-3} \text{ mol} = 1.5 \times 10^{-3} \times 311 \text{ g}$$

$$= 0.4665 \text{ g}$$

Therefore, total mass of the solution = (1000 + 0.4665) g

$$= 1000.4665 \text{ g}$$



This implies that the mass of the solution containing 0.4665 g of nalorphene is 1000.4665 g.

Therefore, mass of the solution containing 1.5 mg of nalorphene is:

$$\frac{1000.4665 \times 1.5 \times 10^{-3}}{0.4665} \text{ g}$$

$$= 3.22 \text{ g}$$

Hence, the mass of aqueous solution required is 3.22 g.

12. Calculate the amount of benzoic acid ( $\text{C}_6\text{H}_5\text{COOH}$ ) required for preparing 250 mL of 0.15 M solution in methanol.

Ans. 0.15 M solution of benzoic acid in methanol means,

1000 mL of solution contains 0.15 mol of benzoic acid

$$\text{Therefore, 250 mL of solution contains} = \frac{0.15 \times 250}{1000} \text{ mol of benzoic acid}$$

$$= 0.0375 \text{ mol of benzoic acid}$$

$$\text{Molar mass of benzoic acid } (\text{C}_6\text{H}_5\text{COOH}) = 7 \times 12 + 6 \times 1 + 2 \times 16$$

$$= 122 \text{ g mol}^{-1}$$

$$\text{Hence, required benzoic acid} = 0.0375 \text{ mol} \times 122 \text{ g mol}^{-1}$$

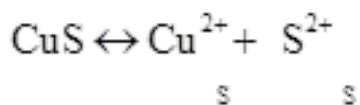
$$= 4.575 \text{ g}$$



13. If the solubility product of CuS is  $6 \times 10^{-16}$ , calculate the maximum molarity of CuS in aqueous solution.

Ans. Solubility product of CuS,  $K_{sp} = 6 \times 10^{-16}$

Let  $s$  be the solubility of CuS in  $\text{mol L}^{-1}$ .



$$\text{Now, } K_{sp} = [\text{Cu}^{2+}][\text{S}^{2-}]$$

$$= \frac{s \times s}{s^2}$$

$$\text{Then, we have, } K_{sp} = s^2 = 6 \times 10^{-16}$$

$$s = \sqrt{6 \times 10^{-16}}$$

$$= 2.45 \times 10^{-8} \text{ mol L}^{-1}$$

Hence, the maximum molarity of CuS in an aqueous solution is  $2.45 \times 10^{-8} \text{ mol L}^{-1}$ .

14. A solution is obtained by mixing 300 g of 25% solution and 400 g of 40% solution by mass. Calculate the mass percentage of the resulting solution.

Ans. Total amount of solute present in the mixture is given by,

$$300 \times \frac{25}{100} + 400 \times \frac{40}{100}$$

$$= 75 + 160$$

$$= 235 \text{ g}$$

Total amount of solution =  $300 + 400 = 700 \text{ g}$

Therefore, mass percentage (w/w) of the solute in the resulting solution,  $= \frac{235}{700} \times 100\%$

$$= 33.57\%$$

And, mass percentage (w/w) of the solvent in the resulting solution,

$$= (100 - 33.57)\%$$

$$= 66.43\%$$

15. Calculate the mass of ascorbic acid (Vitamin C,  $C_6H_8O_6$ ) to be dissolved in 75 g of acetic acid to lower its melting point by  $1.5^\circ\text{C}$ .  $K_f = 3.9 \text{ K kg mol}^{-1}$ .

Ans. Mass of acetic acid,  $w_1 = 75 \text{ g}$

Molar mass of ascorbic acid ( $C_6H_8O_6$ ),  $M_2 = 6 \times 12 + 8 \times 1 + 6 \times 16$

$$= 176 \text{ g mol}^{-1}$$

Lowering of melting point,  $\Delta T_f = 1.5 \text{ K}$

We know that:

$$\Delta T_f = \frac{K_f \times w_2 \times 1000}{M_2 \times w_1}$$

$$w_2 = \frac{\Delta T_f \times M_2 \times w_1}{K_f \times 1000}$$

$$= \frac{1.5 \times 176 \times 75}{3.9 \times 1000}$$

= 5.08 g (approx)

Hence, 5.08 g of ascorbic acid is needed to be dissolved.

16. Calculate the osmotic pressure in pascals exerted by a solution prepared by dissolving 1.0 g of polymer of molar mass 185,000 in 450 mL of water at 37°C .

Ans. It is given that:

Volume of water,  $V = 450 \text{ mL} = 0.45 \text{ L}$

Temperature,  $T = (37 + 273)\text{K} = 310 \text{ K}$

Number of moles of the polymer,  $n = \frac{1}{185000} \text{ mol}$

We know that:

Osmotic pressure,  $\pi = \frac{n}{V} RT$

$$= \frac{1}{185000} \text{ mol} \times \frac{1}{0.45} \times 8.314 \times 10^3 \text{ Pa L K}^{-1} \text{ mol}^{-1} \times 310 \text{ K}$$

= 30.98 Pa

= 31 Pa (approximately)

17. Define the term solution. How many types of solutions are formed? Write briefly about each type with an example.

Ans. Homogeneous mixtures of two or more than two components are known as solutions.



There are three types of solutions.

**(i) Gaseous solution:**

The solution in which the solvent is a gas is called a gaseous solution. In these solutions, the solute may be liquid, solid, or gas. For example, a mixture of oxygen and nitrogen gas is a gaseous solution.

**(ii) Liquid solution:**

The solution in which the solvent is a liquid is known as a liquid solution. The solute in these solutions may be gas, liquid, or solid.

For example, a solution of ethanol in water is a liquid solution.

**(iii) Solid solution:**

The solution in which the solvent is a solid is known as a solid solution. The solute may be gas, liquid or solid. For example, a solution of copper in gold is a solid solution.

18. Calculate the mass of urea ( $\text{NH}_2\text{CONH}_2$ ) required in making 2.5 kg of 0.25 molal aqueous solution.

Ans. Molar mass of urea  $\text{NH}_2\text{CONH}_2 = 2(1 \times 14 + 2 \times 1) + 1 \times 12 + 1 \times 16 = 60 \text{ g mol}^{-1}$

0.25 molar aqueous solution of urea means:

1000 g of water contains 0.25 mol =  $(0.25 \times 60)$  g of urea

= 15 g of urea

That is,

(1000 + 15) g of solution contains 15 g of urea

Therefore, 2.5 kg (2500 g) of solution contains =  $\frac{15 \times 2500}{1000 + 15}$  g

= 36.95 g

= 37 g of urea (approximately)

Hence, mass of urea required = 37 g



## 5 Marks Questions

1. The vapour pressure of  $CS_2$  at  $500^\circ C$  is 854 mm Hg .A solution of 2.0g sulphur in 100g of  $CS_2$  has a vapour pressure of 848.9 mm Hg .Calculate the formula of sulphur molecule.

$$\text{Ans. } P_A^\circ = 854 \text{ mm } P_A = 848.9 \text{ mm}, W_B = 2.0 \text{ g},$$

$$W_A = 100 \text{ g } M_B = ?$$

$$M_A = 12 + 2(32) = 76 \text{ g/mol } (CS_2)$$

$$\frac{P_A^\circ - P_A}{P_A^\circ} = X_B = \frac{W_B}{M_B} / \frac{W_A}{M_A}$$

$$= M_B = W_B \times \frac{W_A}{M_A} \times \frac{P_A^\circ}{P_A^\circ - P_A}$$

$$= 2 \times \frac{100}{76} \times \frac{854}{854 - 848.9}$$

$$= 254.5 \text{ g/mol.}$$

Let the formula =  $S_x$

$$X \times 32 = 254.5 \text{ g/mol}$$

$$X = \frac{254.5}{32}$$

$$= 7.95$$

$$= 8.$$

$$= \text{Formula} = S_8$$

2. Calculate the mass percentage of benzene ( $C_6H_6$ ) and carbon tetrachloride ( $CCl_4$ ) if 22 g of benzene is dissolved in 122 g of carbon tetrachloride.

$$\text{Ans. Mass percentage of } C_6H_6 = \frac{\text{Mass of } C_6H_6}{\text{Total mass of the solution}} \times 100\%$$



$$= \frac{\text{Mass of C}_6\text{H}_6}{\text{Mass of C}_6\text{H}_6 + \text{Mass of CCl}_4} \times 100\%$$

$$= \frac{22}{22 + 122} \times 100\%$$

$$= 15.28\%$$

$$\text{Mass percentage of CCl}_4 = \frac{\text{Mass of CCl}_4}{\text{Total mass of the solution}} \times 100\%$$

$$= \frac{\text{Mass of CCl}_4}{\text{Mass of C}_6\text{H}_6 + \text{Mass of CCl}_4}$$

$$= \frac{122}{22 + 122} \times 100\%$$

$$= 84.72\%$$

Alternatively,

$$\text{Mass percentage of CCl}_4 = (100 - 15.28)\%$$

$$= 84.72\%$$

**3. Calculate the mole fraction of benzene in solution containing 30% by mass in carbon tetrachloride.**

**Ans.** Let the total mass of the solution be 100 g and the mass of benzene be 30 g.

$$\therefore \text{Mass of carbon tetrachloride} = (100 - 30)\text{g}$$

$$= 70 \text{ g}$$

$$\text{Molar mass of benzene (C}_6\text{H}_6) = (6 \times 12 + 6 \times 1) \text{ g mol}^{-1}$$

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

$$\therefore \text{Number of moles of C}_6\text{H}_6 = \frac{30}{78} \text{ mol}$$

$$= 0.3846 \text{ mol}$$

Molar mass of carbon tetrachloride ( $\text{CCl}_4$ ) =  $1 \times 12 + 4 \times 35.5$

$$= 154 \text{ g mol}^{-1}$$

$$\therefore \text{Number of moles of } \text{CCl}_4 = \frac{70}{154} \text{ mol}$$

$$= 0.4545 \text{ mol}$$

Thus, the mole fraction of  $\text{C}_6\text{H}_6$  is given as:

$$\frac{\text{Number of moles of } \text{C}_6\text{H}_6}{\text{Number of moles of } \text{C}_6\text{H}_6 + \text{Number of moles of } \text{CCl}_4}$$
$$= \frac{0.3846}{0.3846 + 0.4545}$$

$$= 0.458$$

4. Calculate the molarity of each of the following solutions: (a) 30 g of  $\text{CO}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  in 4.3 L of solution (b) 30 mL of 0.5 M  $\text{H}_2\text{SO}_4$  diluted to 500 mL.

Ans. Molarity is given by:

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Volume solution in litre}}$$

$$\text{(a) Molar mass of } \text{CO}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O} = 59 + 2(14 + 3 \times 16) + 6 \times 18$$

$$= 291 \text{ g mol}^{-1}$$

$$\text{Therefore, Moles of } \text{CO}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O} = \frac{30}{291} \text{ mol}$$

$$= 0.103 \text{ mol}$$

$$\text{Therefore, molarity} = \frac{0.103 \text{ mol}}{4.3 \text{ L}}$$

$$= 0.023 \text{ M}$$

**(b)** Number of moles present in 1000 mL of 0.5 M  $\text{H}_2\text{SO}_4 = 0.5 \text{ mol}$

$$\therefore \text{Number of moles present in 30 mL of 0.5 M } \text{H}_2\text{SO}_4 = \frac{0.5 \times 30}{1000} \text{ mol}$$

$$= 0.015 \text{ mol}$$

$$\text{Therefore, molarity} = \frac{0.015}{0.5 \text{ L}} \text{ mol}$$

$$= 0.03 \text{ M}$$

**5. Calculate (a) molality (b) molarity and (c) mole fraction of KI if the density of 20% (mass/mass) aqueous KI is  $1.202 \text{ g ml}^{-1}$ .**

**Ans. (a)** Molar mass of KI =  $39 + 127 = 166 \text{ g mol}^{-1}$

20% (mass/mass) aqueous solution of KI means 20 g of KI is present in 100 g of solution.

That is,

20 g of KI is present in  $(100 - 20) \text{ g}$  of water = 80 g of water

$$\text{Therefore, molality of the solution} = \frac{\text{Moles of KI}}{\text{Mass of water in kg}}$$

$$\frac{\frac{20}{166} \text{ mol}}{0.08}$$

$$= 1.506 \text{ m}$$

$$= 1.51 \text{ m (approximately)}$$

**(b)** It is given that the density of the solution =  $1.202 \text{ g ml}^{-1}$

$$\text{Therefore, Volume of 100 g solution} = \frac{\text{Mass}}{\text{Density}}$$

$$= \frac{100\text{g}}{1.202\text{ g ml}^{-1}}$$

$$= 83.19\text{ mL}$$

$$= 83.19 \times 10^{-3}\text{L}$$

$$\text{Therefore, molarity of the solution} = \frac{\frac{20}{166}\text{ mol}}{83.19 \times 10^{-3}\text{ L}}$$

$$= 1.45\text{ M}$$

$$\text{(c) Moles of KI} = \frac{20}{166} = 0.12\text{ mol}$$

$$\text{Moles of water} = \frac{80}{18} = 4.44\text{ mol}$$

$$\text{Therefore, mole fraction of KI} = \frac{\text{Moles of KI}}{\text{Moles of KI} + \text{Moles of water}}$$

$$= \frac{0.12}{0.12 + 4.44}$$

$$= 0.0263$$

**6.  $\text{H}_2\text{S}$ , a toxic gas with rotten egg like smell, is used for the qualitative analysis. If the solubility of  $\text{H}_2\text{S}$  in water at STP is 0.195 m, calculate Henry's law constant.**

**Ans.** It is given that the solubility of  $\text{H}_2\text{S}$  in water at STP is 0.195 m, i.e., 0.195 mol of  $\text{H}_2\text{S}$  is dissolved in 1000 g of water.

$$\text{Moles of water} = \frac{1000\text{g}}{18\text{ g mol}^{-1}}$$

$$= 55.56 \text{ mol}$$

$$\therefore \text{Mole fraction of H}_2\text{S}, x = \frac{\text{Moles of H}_2\text{S}}{\text{Moles of H}_2\text{S} + \text{Moles of water}}$$

$$= \frac{0.195}{0.195 + 55.56}$$

$$= 0.0035$$

At STP, pressure ( $p$ ) = 0.987 bar

According to Henry's law:

$$p = K_H x$$

$$K_H = \frac{p}{x}$$
$$= \frac{0.987}{0.0035} \text{ bar}$$

$$= 282 \text{ bar}$$

**7. Henry's law constant for  $\text{CO}_2$  in water is  $1.67 \times 10^8 \text{ Pa}$  at  $298 \text{ K}$ . Calculate the quantity of  $\text{CO}_2$  in  $500 \text{ mL}$  of soda water when packed under  $2.5 \text{ atm}$   $\text{CO}_2$  pressure at  $298 \text{ K}$ .**

**Ans.** It is given that:

$$K_H = 1.67 \times 10^8 \text{ Pa}$$

$$P_{\text{CO}_2} = 2.5 \text{ atm} = 2.5 \times 1.01325 \times 10^5 \text{ Pa}$$

$$= 2.533125 \times 10^5 \text{ Pa}$$

According to Henry's law:

$$P_{\text{CO}_2} = K_H x$$

$$x = \frac{P_{\text{CO}_2}}{K_H}$$

$$\frac{2.533125 \times 10^5}{1.67 \times 10^8}$$

$$= 0.00152$$

$$\text{We can write, } x = \frac{n_{\text{CO}_2}}{n_{\text{CO}_2} + n_{\text{H}_2\text{O}}} \approx \frac{n_{\text{CO}_2}}{n_{\text{H}_2\text{O}}}$$

[Since,  $n_{\text{CO}_2}$  is negligible as compared to  $n_{\text{H}_2\text{O}}$  ]

In 500 mL of soda water, the volume of water = 500 mL

[Neglecting the amount of soda present]

We can write:

500 mL of water = 500 g of water

$$= \frac{500}{18} \text{ mol of water}$$

$$= 27.78 \text{ mol of water}$$

$$\text{Now, } \frac{n_{\text{CO}_2}}{n_{\text{H}_2\text{O}}} = x$$

$$\frac{n_{\text{CO}_2}}{27.78} = 0.00152$$

$$n_{\text{CO}_2} = 0.042 \text{ mol}$$

Hence, quantity of  $\text{CO}_2$  in 500 mL of soda water =  $(0.042 \times 44) \text{ g}$

$$= 1.848 \text{ g}$$

8. The vapour pressure of pure liquids A and B are 450 and 700 mm Hg respectively, at 350 K. Find out the composition of the liquid mixture if total vapour pressure is 600 mm Hg. Also find the composition of the vapour phase.

Ans. It is given that:

$$P_A^{\circ} = 450 \text{ mm of Hg}$$

$$P_B^{\circ} = 700 \text{ mm of Hg}$$

$$P_{\text{total}} = 600 \text{ mm of Hg}$$

From Raoult's law, we have:

$$p_A = p_A^{\circ} x_A$$

$$p_B = p_B^{\circ} x_B = p_B^{\circ} (1 - x_A)$$

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

$$p_{\text{total}} = p_A^{\circ} x_A + p_B^{\circ} (1 - x_A)$$

$$p_{\text{total}} = p_A^{\circ} x_A + p_B^{\circ} - p_B^{\circ} x_A$$
$$p_{\text{total}} = (p_A^{\circ} - p_B^{\circ}) x_A + p_B^{\circ}$$

$$p_{\text{total}} = (p_A^{\circ} - p_B^{\circ}) x_A + p_B^{\circ}$$

$$600 = (450 - 700) x_A + 700$$

$$-100 = -250 x_A$$

$$x_A = 0.4$$

Therefore,  $x_B = 1 - x_A$

$$= 1 - 0.4$$

$$= 0.6$$



$$\text{Now, } p_A = p_A^\circ \times x_A$$

$$= 450 \times 0.4$$

$$= 180 \text{ mm of Hg}$$

$$p_B = p_B^\circ \times x_B$$

$$= 700 \times 0.6$$

$$= 420 \text{ mm of Hg}$$

Now, in the vapour phase:

$$\text{Mole fraction of liquid A} = \frac{p_A}{p_A + p_B}$$

$$\frac{180}{180 + 420}$$

$$= \frac{180}{600}$$

$$= 0.30$$

And, mole fraction of liquid B = 1 - 0.30

**9. Vapour pressure of pure water at 298 K is 23.8 mm Hg. 50 g of urea ( $\text{NH}_2\text{CONH}_2$ ) is dissolved in 850 g of water. Calculate the vapour pressure of water for this solution and**

Molecular weight of urea,  $M_2 = 60 \text{ g mol}^{-1}$

Now, we have to calculate vapour pressure of water in the solution. We take vapour pressure as  $p_1$ .

Now, from Raoult's law, we have:

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



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

$$\frac{23.8 - p_1}{23.8} = \frac{\frac{50}{60}}{\frac{850}{18} + \frac{50}{60}}$$

$$\frac{23.8 - p_1}{23.8} = \frac{0.83}{47.22 + 0.83}$$

$$\frac{23.8 - p_1}{23.8} = 0.0173$$

$$p_1 = 23.4 \text{ mm of Hg}$$

Hence, the vapour pressure of water in the given solution is 23.4 mm of Hg and its relative lowering is 0.0173.

**10. Boiling point of water at 750 mm Hg is  $99.63^\circ\text{C}$ . How much sucrose is to be added to 500 g of water such that it boils at  $100^\circ\text{C}$ . Molal elevation constant for water is  $0.52 \text{ K kg mol}^{-1}$ .**

**Ans.** Here, elevation of boiling point  $\Delta T_b = (100 + 273) - (99.63 + 273)$

$$= 0.37 \text{ K}$$

Mass of water,  $w_1 = 500 \text{ g}$

Molar mass of sucrose ( $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ ),  $M_2 = 11 \times 12 + 22 \times 1 + 11 \times 16$

$$= 342 \text{ g mol}^{-1}$$

Molal elevation constant,  $K_b = 0.52 \text{ K kg mol}^{-1}$

We know that:



$$\Delta T_b = \frac{K_b \times 1000 \times w_2}{M_2 \times w_1}$$

$$w_2 = \frac{\Delta T_b \times M_2 \times w_1}{K_b \times 1000}$$

$$= \frac{0.37 \times 342 \times 500}{0.52 \times 1000}$$

= 121.67 g (approximately)

Hence, 121.67 g of sucrose is to be added.

**11. Define the following terms:**

**(i) Mole fraction**

**(ii) Molality**

**(iii) Molarity**

**(iv) Mass percentage.**

**Ans. (i) Mole fraction:**

The mole fraction of a component in a mixture is defined as the ratio of the number of moles of the component to the total number of moles of all the components in the mixture.

i.e.,

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

Mole fraction is denoted by 'x'.

If in a binary solution, the number of moles of the solute and the solvent are  $n_A$  and  $n_B$  respectively, then the mole fraction of the solute in the solution is given by,

$$x_A = \frac{n_A}{n_A + n_B}$$

Similarly, the mole fraction of the solvent in the solution is given as:

$$x_B = \frac{n_B}{n_A + n_B}$$

### (ii) Molality

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

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

### (iii) Molarity

Molarity (M) is defined as the number of moles of the solute dissolved in one Litre of the solution.

It is expressed as:

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

### (iv) Mass percentage:

The mass percentage of a component of a solution is defined as the mass of the solute in grams present in 100 g of the solution. It is expressed as:

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

12. Concentrated nitric acid used in laboratory work is 68% nitric acid by mass in aqueous solution. What should be the molarity of such a sample of the acid if the density of the solution is  $1.504 \text{ g mL}^{-1}$ ?

$$\text{Molarity of solution} = \frac{1.079 \text{ mol}}{66.49 \times 10^{-3} \text{ L}}$$

$$= 16.23 \text{ M}$$

**Ans.** Concentrated nitric acid used in laboratory work is 68% nitric acid by mass in an aqueous solution. This means that 68 g of nitric acid is dissolved in 100 g of the solution.

$$\text{Molar mass of nitric acid (HNO}_3\text{)} = 1 \times 1 + 1 \times 14 + 3 \times 16 = 63 \text{ g mol}^{-1}$$

$$\text{Then, number of moles of HNO}_3 = \frac{68}{63} \text{ mol}$$

$$= 1.079 \text{ mol}$$

Given,

$$\text{Density of solution} = 1.504 \text{ g mL}^{-1}$$

$$\text{Therefore, Volume of 100 g solution} = \frac{100}{1.504} \text{ mL}$$

$$= 66.49 \text{ mL}$$

$$= 66.49 \times 10^{-3} \text{ L}$$

$$\text{Molarity of solution} = \frac{1.079 \text{ mol}}{66.49 \times 10^{-3} \text{ L}}$$

$$= 16.23 \text{ M}$$



13. 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  $1.2 \text{ g ml}^{-1}$ , then what shall be the molarity of the solution?

**Ans.** 10% w/w solution of glucose in water means that 10 g of glucose is present in 100 g of the solution i.e., 10 g of glucose is present in  $(100 - 10) \text{ g} = 90 \text{ g}$  of water.

Molar mass of glucose ( $\text{C}_6\text{H}_{12}\text{O}_6$ ) =  $6 \times 12 + 12 \times 1 + 6 \times 16 = 180 \text{ g mol}^{-1}$

Then, number of moles of glucose =  $\frac{10}{180} \text{ mol}$

= 0.056 mol

Molality of solution =  $\frac{0.056 \text{ mol}}{0.09 \text{ kg}} = 0.62 \text{ m}$

Number of moles of water =  $\frac{90 \text{ g}}{18 \text{ g mol}^{-1}}$

= 5 mol

Mole fraction of glucose ( $x_g$ ) =  $\frac{0.056}{0.056 + 5}$

= 0.011

And, mole fraction of water  $x_w = 1 - x_g$

=  $1 - 0.011$

= 0.989

If the density of the solution is  $1.2 \text{ g ml}^{-1}$ , then the volume of the 100 g solution can be given as:

=  $\frac{100 \text{ g}}{1.2 \text{ g ml}^{-1}}$

$$= 83.33 \text{ mL}$$

$$= 83.33 \times 10^{-3} \text{ L}$$

$$\therefore \text{Molarity of the solution} = \frac{0.056 \text{ mol}}{83.33 \times 10^{-3} \text{ L}}$$

$$= 0.67 \text{ M}$$

**14. How many mL of 0.1 M HCl are required to react completely with 1 g mixture of  $\text{Na}_2\text{CO}_3$  and  $\text{NaHCO}_3$  containing equimolar amounts of both?**

**Ans.** Let the amount of  $\text{Na}_2\text{CO}_3$  in the mixture be  $x$  g.

Then, the amount of  $\text{NaHCO}_3$  in the mixture is  $(1 - x)$  g.

$$\text{Molar mass of } \text{Na}_2\text{CO}_3 = 2 \times 23 + 1 \times 12 + 3 \times 16$$

$$= 106 \text{ g mol}^{-1}$$

$$\therefore \text{Number of moles } \text{Na}_2\text{CO}_3 = \frac{x}{106} \text{ mol}$$

$$\text{Molar mass of } \text{NaHCO}_3 = 1 \times 23 + 1 \times 1 \times 12 + 3 \times 16$$

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

$$\text{Number of moles of } \text{NaHCO}_3 = \frac{1-x}{84} \text{ mol}$$

According to the question,

$$\frac{x}{106} = \frac{1-x}{84}$$

$$\Rightarrow 84x = 106 - 106x$$

$$\Rightarrow 190x = 106$$

$$\Rightarrow x = 0.5579$$

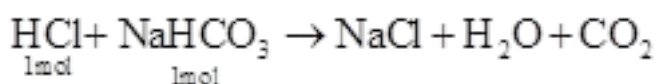
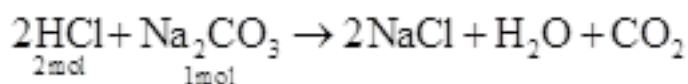
$$\text{Therefore, number of moles of } \text{Na}_2\text{CO}_3 = \frac{0.5579}{106} \text{ mol}$$

= 0.0053 mol

And, number of moles of  $\text{NaHCO}_3 = \frac{1 - 0.5579}{84}$

= 0.0053 mol

HCl reacts with  $\text{Na}_2\text{CO}_3$  and  $\text{NaHCO}_3$  according to the following equation.



1 mol of  $\text{Na}_2\text{CO}_3$  reacts with 2 mol of HCl.

Therefore, 0.0053 mol of  $\text{Na}_2\text{CO}_3$  reacts with  $2 \times 0.0053 \text{ mol} = 0.0106 \text{ mol}$ .

Similarly, 1 mol of  $\text{NaHCO}_3$  reacts with 1 mol of HCl.

Therefore, 0.0053 mol of  $\text{NaHCO}_3$  reacts with 0.0053 mol of HCl.

Total moles of HCl required =  $(0.0106 + 0.0053) \text{ mol}$

= 0.0159 mol

In 0.1 M of HCl,

0.1 mol of HCl is present in 1000 mL of the solution.

Therefore, 0.0159 mol of HCl is present in  $\frac{1000 \times 0.0159}{0.1} \text{ mol}$

= 159 mL of the solution

Hence, 159 mL of 0.1 M of HCl is required to react completely with 1 g mixture of  $\text{Na}_2\text{CO}_3$  and  $\text{NaHCO}_3$ , containing equimolar amounts of both.



15. An antifreeze solution is prepared from 222.6 g of ethylene glycol ( $C_2H_6O_2$ ) and 200 g of water. Calculate the molality of the solution. If the density of the solution is  $1.072 \text{ g mL}^{-1}$ , then what shall be the molarity of the solution?

**Ans.** Molar mass of ethylene glycol  $[C_2H_4(OH)_2] = 2 \times 12 + 6 \times 1 + 2 \times 16$

$$= 62 \text{ g mol}^{-1}$$

$$\text{Number of moles of ethylene glycol} = \frac{222.6 \text{ g}}{62 \text{ g mol}^{-1}}$$

$$= 3.59 \text{ mol}$$

$$\text{Therefore, molality of the solution} = \frac{3.59 \text{ mol}}{0.200 \text{ kg}}$$

$$= 17.95 \text{ m}$$

$$\text{Total mass of the solution} = (222.6 + 200) \text{ g}$$

$$= 422.6 \text{ g}$$

Given,

$$\text{Density of the solution} = 1.072 \text{ g mL}^{-1}$$

$$\text{Therefore, Volume of the solution} = \frac{422.6 \text{ g}}{1.072 \text{ g mL}^{-1}}$$

$$= 394.22 \text{ mL}$$

$$= 0.3942 \times 10^{-3} \text{ L}$$

$$\text{Molarity of the solution} = \frac{3.59 \text{ mol}}{0.39422 \times 10^{-3} \text{ L}}$$

$$= 9.11 \text{ M}$$

## 16. State Henry's law and mention some important applications?

**Ans.** Henry's law states that partial pressure of a gas in the vapour phase is proportional to the mole fraction of the gas in the solution. If  $p$  is the partial pressure of the gas in the vapour phase and  $x$  is the mole fraction of the gas, then Henry's law can be expressed as:

$$p = K_H x$$

Where,

$K_H$  is Henry's law constant

Some important applications of Henry's law are mentioned below.

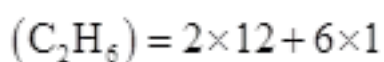
**(i)** Bottles are sealed under high pressure to increase the solubility of  $\text{CO}_2$  in soft drinks and soda water.

**(ii)** Henry's law states that the solubility of gases increases with an increase in pressure. Therefore, when a scuba diver dives deep into the sea, the increased sea pressure causes the nitrogen present in air to dissolve in his blood in great amounts. As a result, when he comes back to the surface, the solubility of nitrogen again decreases and the dissolved gas is released, leading to the formation of nitrogen bubbles in the blood. This results in the blockage of capillaries and leads to a medical condition known as 'bends' or 'decompression sickness'.

Hence, the oxygen tanks used by scuba divers are filled with air and diluted with helium to avoid bends.

**(iii)** The concentration of oxygen is low in the blood and tissues of people living at high altitudes such as climbers. This is because at high altitudes, partial pressure of oxygen is less than that at ground level. Low-blood oxygen causes climbers to become weak and disables them from thinking clearly. These are symptoms of anoxia

**17. The partial pressure of ethane over a solution containing  $6.56 \times 10^{-3}$  g of ethane is 1 bar. If the solution contains  $5.00 \times 10^{-2}$  g of ethane, then what shall be the partial pressure of the gas?**



**Ans.** Molar mass of ethane

$$= 30 \text{ g mol}^{-1}$$

$$\therefore \text{Number of moles present in } 6.56 \times 10^{-3} \text{ g of ethane} = \frac{6.56 \times 10^{-3}}{30}$$

$$= 2.187 \times 10^{-4} \text{ mol}$$

Let the number of moles of the solvent be  $x$ .

According to Henry's law,

$$p = K_H x$$

$$1 \text{ bar} = K_H \frac{2.187 \times 10^{-4}}{2.187 \times 10^{-4} + x}$$

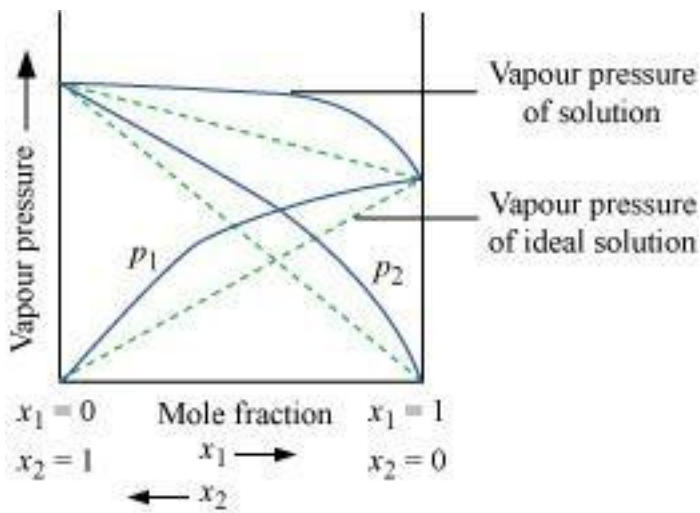
$$1 \text{ bar} = K_H \frac{2.187 \times 10^{-4}}{x} \quad (\text{Since } x \gg 2.187 \times 10^{-4})$$

$$K_H = \frac{x}{2.187 \times 10^{-4}} \text{ bar}$$

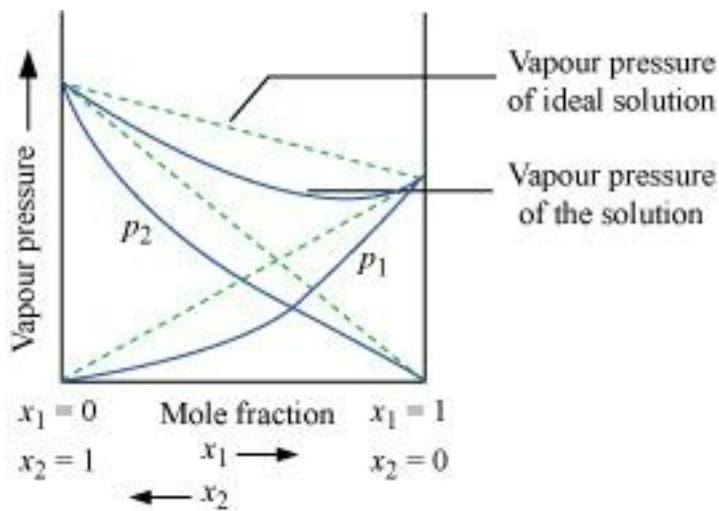
**18. What is meant by positive and negative deviations from Raoult's law and how is the sign of  $\Delta_{\text{Sol}}H$  related to positive and negative deviations from Raoult's law?**

**Ans.** According to Raoult's law, the partial vapour pressure of each volatile component in any solution is directly proportional to its mole fraction. The solutions which obey Raoult's law over the entire range of concentration are known as ideal solutions. The solutions that do not obey Raoult's law (non-ideal solutions) have vapour pressures either higher or lower than that predicted by Raoult's law. If the vapour pressure is higher, then the solution is said to exhibit positive deviation, and if it is lower, then the solution is said to exhibit negative deviation from Raoult's law.





**Vapour pressure of a two-component solution showing positive deviation from Raoult's law**



**Vapour pressure of a two-component solution showing negative deviation from Raoult's law**

In the case of an ideal solution, the enthalpy of the mixing of the pure components for forming the solution is zero.

$$\Delta_{\text{sol}}H = 0$$

In the case of solutions showing positive deviations, absorption of heat takes place.

Therefore,  $\Delta\text{SolH} = \text{Positive}$

In the case of solutions showing negative deviations, evolution of heat takes place.

Therefore,  $\Delta\text{SolH} = \text{Negative}$

**19. 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.** Vapour pressure of the solution at normal boiling point ( $p_1$ ) = 1.004 bar

Vapour pressure of pure water at normal boiling point ( $p_1^0$ ) = 1.013 bar

Mass of solute, ( $w_2$ ) = 2 g

Mass of solvent (water), ( $w_1$ ) = 98 g

Molar mass of solvent (water), ( $M_1$ ) = 18 g mol<sup>-1</sup>

According to Raoult's law,

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

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

$$\frac{0.009}{1.013} = \frac{2 \times 18}{M_2 \times 98}$$

$$M_2 = \frac{1.013 \times 2 \times 18}{0.009 \times 98}$$

$$= 41.35 \text{ g mol}^{-1}$$

Hence, the molar mass of the solute is 41.35 g mol<sup>-1</sup>.

**20. Heptane and octane form an ideal solution. At 373 K, the vapour pressures of the two liquid components are 105.2 kPa and 46.8 kPa respectively. What will be the vapour pressure of a mixture of 26.0 g of heptane and 35 g of octane?**

**Ans.** Vapour pressure of heptanes ( $p_1^0$ ) = 105.2 kPa

Vapour pressure of octane ( $p_2^0$ ) = 46.8 kPa

We know that,

Molar mass of heptane ( $C_7H_{16}$ ) =  $7 \times 12 + 16 \times 1$

= 100 g mol<sup>-1</sup>

Therefore, Number of moles of heptane =  $\frac{26}{100}$  mol

= 0.26 mol

Molar mass of octane ( $C_8H_{18}$ ) =  $8 \times 12 + 18 \times 1$

= 114 g mol<sup>-1</sup>

Therefore, Number of moles of octane =  $\frac{35}{114}$  mol

= 0.31 mol

Mole fraction of heptane,  $x_1 = \frac{0.26}{0.26 + 0.31}$

= 0.456

And, mole fraction of octane,  $x_2 = 1 - 0.456$

= 0.544

Now, partial pressure of heptane,  $p_1 = x_1 p_1^0$

$$= 0.456 \times 105.2$$

$$= 47.97 \text{ kPa}$$

Partial pressure of octane,  $p_2 = x_2 p_2^0$

$$= 0.544 \times 46.8$$

$$= 25.46 \text{ kPa}$$

Hence, vapour pressure of solution,  $p_{\text{total}} = p_1 + p_2$

$$= 47.97 + 25.46$$

$$= 73.43 \text{ kPa}$$

**21. The vapour pressure of water is 12.3 kPa at 300 K. Calculate vapour pressure of 1 molal solution of a non-volatile solute in it.**

**Ans.** 1 molal solution means 1 mol of the solute is present in 1000 g of the solvent (water).

Molar mass of water =  $18 \text{ g mol}^{-1}$

Therefore, Number of moles present in 1000 g of water =  $\frac{1000}{18}$

$$= 55.56 \text{ mol}$$

Therefore, mole fraction of the solute in the solution is

$$x_2 = \frac{1}{1+55.56} = 0.0177.$$

It is given that,

Vapour pressure of water,  $(p_1^0) = 12.3 \text{ kPa}$

Applying the relation,  $\frac{p_1^\circ - p_1}{p_1^\circ} = x_2$

$$\frac{12.3 - p_1}{12.3} = 0.0177$$

$$\Rightarrow 12.3 - p_1 = 0.2177$$

$$\Rightarrow p_1 = 12.0823$$

$$= 12.08 \text{ kPa (approximately)}$$

Hence, the vapour pressure of the solution is 12.08 kPa.

**22. Calculate the mass of a non-volatile solute (molar mass  $40 \text{ g mol}^{-1}$ ) which should be dissolved in 114 g octane to reduce its vapour pressure to 80%.**

**Ans.** Let the vapour pressure of pure octane be  $p_1^\circ$

Then, the vapour pressure of the octane after dissolving the non-volatile solute is

$$\frac{80}{100} p_1^\circ = 0.8 p_1^\circ$$

Molar mass of solute,  $M_2 = 40 \text{ g mol}^{-1}$

Mass of octane,  $w_1 = 114 \text{ g}$

Molar mass of octane, ( $\text{C}_8\text{H}_{18}$ ),  $M_1 = 8 \times 12 + 18 \times 1$

$$= 114 \text{ g mol}^{-1}$$

Applying the relation,

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



$$\frac{p_1^\circ - 0.8p_1^\circ}{p_1^\circ} = \frac{w_2 \times 114}{40 \times 114}$$

$$\frac{0.2p_1^\circ}{p_1^\circ} = \frac{w_2}{40}$$

$$0.2 = \frac{w_2}{40}$$

$$w_2 = 8 \text{ g}$$

Hence, the required mass of the solute is 8 g.

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

**1. molar mass of the solute**

**2. vapour pressure of water at 298 K.**

**Ans. (i)** Let, the molar mass of the solute be  $M \text{ g mol}^{-1}$

Now, the no. of moles of solvent (water),  $n_1 = \frac{90 \text{ g}}{18 \text{ g mol}^{-1}} = 5 \text{ mol}$

And, the no. of moles of solute,  $n_2 = \frac{30 \text{ g}}{M \text{ mol}^{-1}} = \frac{30}{M} \text{ mol}$

$$p_1 = 2.8 \text{ kPa}$$

Applying the relation:

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

$$\frac{p_1^{\circ} - 2.8}{p_1^{\circ}} = \frac{\frac{30}{M}}{5 + \frac{30}{M}}$$

$$1 - \frac{2.8}{p_1^{\circ}} = \frac{\frac{30}{M}}{\frac{5M + 30}{M}}$$

$$1 - \frac{2.8}{p_1^{\circ}} = \frac{30}{5M + 30}$$

$$\frac{2.8}{p_1^{\circ}} = 1 - \frac{30}{5M + 30}$$

$$\frac{2.8}{p_1^{\circ}} = \frac{5M + 30 - 30}{5M + 30}$$

$$\frac{2.8}{p_1^{\circ}} = \frac{5M}{5M + 30}$$

$$\frac{p_1^{\circ}}{2.8} = \frac{5M + 30}{5M} \dots\dots\dots(i)$$

After the addition of 18 g of water:

$$n_1 = \frac{90 + 18g}{18} = 6 \text{ mol}$$

$$p_1 = 2.9 \text{ kPa}$$

Again, applying the relation:

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

$$\frac{p_1^0 - 2.9}{p_1^0} = \frac{\frac{30}{M}}{6 + \frac{30}{M}}$$

$$1 - \frac{2.9}{p_1^0} = \frac{\frac{30}{M}}{\frac{6M + 30}{M}}$$

$$1 - \frac{2.9}{p_1^0} = \frac{30}{6M + 30}$$

$$\frac{2.9}{p_1^0} = 1 - \frac{30}{6M + 30}$$

$$\frac{2.9}{p_1^0} = \frac{6M + 30 - 30}{6M + 30}$$

$$\frac{2.9}{p_1^0} = \frac{6M}{6M + 30}$$

$$\frac{p_1^0}{2.9} = \frac{6M + 30}{6M} \dots\dots\dots(ii)$$

Dividing equation (i) by (ii), we have:

$$\frac{2.9}{2.8} = \frac{\frac{5M + 30}{6M + 30}}{\frac{6M}{6M + 30}}$$

$$\frac{2.9}{2.8} \times \frac{6M + 30}{6} = \frac{5M + 30}{5}$$

$$2.9 \times 5 \times (6M + 30) = 2.8 \times 6 \times (5M + 30)$$

$$87M + 435 = 84M + 504$$

$$3M = 69$$

$$M = 23u$$

Therefore, the molar mass of the solute is  $23 \text{ g mol}^{-1}$ .

(ii) Putting the value of  $\tilde{A}\hat{c}\hat{a}, -\tilde{E}\tilde{c}\tilde{e}M'$  in equation (i), we have:

$$\frac{p_1^0}{2.8} = \frac{5 \times 23 + 30}{5 \times 23}$$

$$\frac{p_1^0}{2.8} = \frac{145}{115}$$

$$p_1^0 = 3.53$$

Hence, the vapour pressure of water at 298 K is 3.53 kPa.

**24. A 5% solution (by mass) of cane sugar in water has freezing point of 271 K. Calculate the freezing point of 5% glucose in water if freezing point of pure water is 273.15 K.**

**Ans.** Here,  $\Delta T_f = (273.15 - 271) \text{ K}$

$$= 2.15 \text{ K}$$

Molar mass of sugar ( $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ ) =  $12 \times 12 + 22 \times 1 + 11 \times 16$

$$= 342 \text{ g mol}^{-1}$$

5% solution (by mass) of cane sugar in water means 5 g of cane sugar is present in  $(100 - 5) \text{ g} = 95 \text{ g}$  of water.

$$\text{Now, number of moles of cane sugar} = \frac{5}{342} \text{ mol}$$

$$= 0.0146 \text{ mol}$$

$$\text{Therefore, molality of the solution, } m = \frac{0.0146 \text{ mol}}{0.095 \text{ kg}}$$

$$= 0.1537 \text{ mol kg}^{-1}$$

Applying the relation,

$$\Delta T_f = K_f \times m$$

$$K_f = \frac{\Delta T_f}{m}$$

$$= \frac{2.15 \text{ K}}{0.1537 \text{ mol kg}^{-1}}$$

$$= 13.99 \text{ K kg mol}^{-1}$$

Molar of glucose ( $\text{C}_6\text{H}_{12}\text{O}_6$ ) =  $6 \times 12 + 12 \times 1 + 6 \times 16$

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

5% glucose in water means 5 g of glucose is present in  $(100 - 5) \text{ g} = 95 \text{ g}$  of water.

$$\text{Therefore, Number of moles of glucose} = \frac{5}{180} \text{ mol}$$

$$= 0.0278 \text{ mol}$$

$$\text{Therefore, molality of the solution, } m = \frac{0.0278 \text{ mol}}{0.095 \text{ kg}}$$

$$= 0.2926 \text{ mol kg}^{-1}$$

Applying the relation,

$$\Delta T_f = K_f \times m$$

$$= 13.99 \text{ K kg mol}^{-1} \times 0.2926 \text{ mol kg}^{-1}$$

$$= 4.09 \text{ K (approximately)}$$

Hence, the freezing point of 5% glucose solution is  $(273.15 - 4.09) \text{ K} = 269.06 \text{ K}$ .

25. Two elements A and B form compounds having formula AB<sub>2</sub> and AB<sub>4</sub>. When dissolved in 20 g of benzene (C<sub>6</sub>H<sub>6</sub>), 1 g of AB<sub>2</sub> lowers the freezing point by 2.3 K whereas 1.0 g of AB<sub>4</sub> lowers it by 1.3 K. The molar depression constant for benzene is 5.1 K kg mol<sup>-1</sup>. Calculate atomic masses of A and B.

Ans. We know that,

$$M_2 = \frac{1000 \times w_2 \times k_f}{\Delta T_f \times w_1}$$

$$\text{Then, } M_{AB_2} = \frac{1000 \times 1 \times 5.1}{2.3 \times 20}$$

$$= 110.87 \text{ g mol}^{-1}$$

$$M_{AB_4} = \frac{1000 \times 1 \times 5.1}{1.3 \times 20}$$

$$= 196.15 \text{ g mol}^{-1}$$

Now, we have the molar masses of AB<sub>2</sub> and AB<sub>4</sub> as 110.87 g mol<sup>-1</sup> and 196.15 g mol<sup>-1</sup> respectively.

Let the atomic masses of A and B be x and y respectively.

Now, we can write:

$$x + 2y = 110.87 \dots\dots\dots\text{(i)}$$

$$x + 4y = 196.15 \dots\dots\dots\text{(ii)}$$

Subtracting equation (i) from (ii), we have

$$2y = 85.28$$

$$\Rightarrow y = 42.64$$

Putting the value of 'y' in equation (1), we have

$$x + 2 \times 42.64 = 110.87$$

$$\Rightarrow x = 25.59$$

Hence, the atomic masses of A and B are 25.59 u and 42.64 u respectively.

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

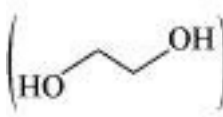
**(i) phenol (ii) toluene (iii) formic acid**

**(iv) ethylene glycol (v) chloroform (vi) pentanol.**

**Ans. (i)** Phenol ( $C_6H_5OH$ ) has the polar group -OH and non-polar group  $-C_6H_5$ . Thus, phenol is partially soluble in water.

**(ii)** Toluene ( $C_6H_5 - CH_3$ ) has no polar groups. Thus, toluene is insoluble in water.

**(iii)** Formic acid (HCOOH) has the polar group -OH and can form H-bond with water. Thus, formic acid is highly soluble in water.

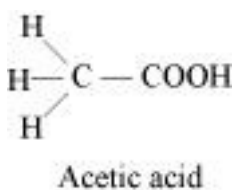
**(iv)** Ethylene glycol  has polar -OH group and can form H-bond. Thus, it is highly soluble in water.

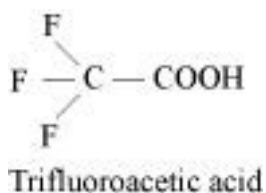
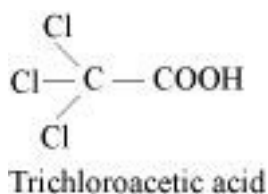
**(v)** Chloroform is insoluble in water.

**(vi)** Pentanol ( $C_5H_{11}OH$ ) has polar -OH group, but it also contains a very bulky non-polar  $-C_5H_{11}$  group. Thus, pentanol is partially soluble in water.

**27. The depression in freezing point of water observed for the same amount of acetic acid, trichloroacetic acid and trifluoroacetic acid increases in the order given above. Explain briefly.**

**Ans.**





Among H, Cl, and F, H is least electronegative while F is most electronegative. Then, F can withdraw electrons towards itself more than Cl and H. Thus, trifluoroacetic acid can easily lose  $\text{H}^+$  ions i.e., trifluoroacetic acid ionizes to the largest extent. Now, the more ions produced, the greater is the depression of the freezing point. Hence, the depression in the freezing point increases in the order:

Acetic acid < trichloroacetic acid < trifluoroacetic acid

**28. Calculate the depression in the freezing point of water when 10 g of  $\text{CH}_3\text{CH}_2\text{CHClCOOH}$  is added to 250 g of water.  $K_a = 1.4 \times 10^{-3}$ ,  $K_f = 1.86 \text{ K kg mol}^{-1}$ .**

**Ans.** Molar mass of  $\text{CH}_3\text{CH}_2\text{CHClCOOH} = 15 + 14 + 13 + 35.5 + 12 + 16 + 16 + 1$   
 $= 122.5 \text{ g mol}^{-1}$

Therefore, No. of moles present in 10 g of  $\text{CH}_3\text{CH}_2\text{CHClCOOH} = \frac{10 \text{ g}}{122.5 \text{ g mol}^{-1}}$

$= 0.0816 \text{ mol}$

It is given that 10 g of  $\text{CH}_3\text{CH}_2\text{CHClCOOH}$  is added to 250 g of water.

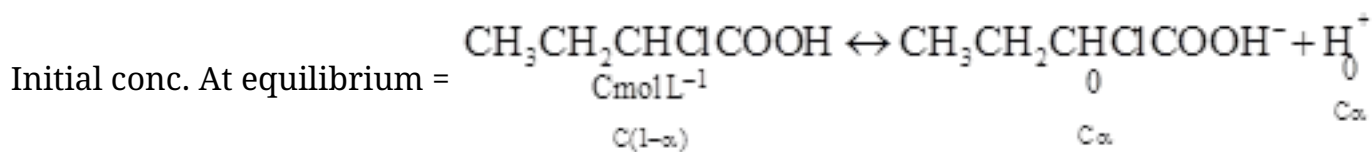
Therefore, Molality of the solution,  $= \frac{0.0816}{0.250} \times 1000$

$= 0.3264 \text{ mol kg}^{-1}$



Let  $\alpha$  be the degree of dissociation of  $\text{CH}_3\text{CH}_2\text{CHClCOOH}$

$\text{CH}_3\text{CH}_2\text{CHClCOOH}$  undergoes dissociation according to the following equation:



$$K_a = \frac{C\alpha \cdot C\alpha}{C(1-\alpha)}$$

$$= \frac{C\alpha^2}{1-\alpha}$$

Since  $\alpha$  is very small with respect to 1,  $1 - \alpha \approx 1$

$$K_a = \frac{C\alpha^2}{1}$$

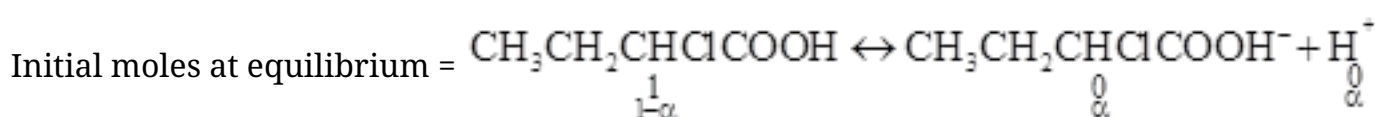
Now,  $K_a = C\alpha^2$

$$\alpha = \sqrt{\frac{K_a}{C}}$$

$$= \sqrt{\frac{1.4 \times 10^{-3}}{0.3264}} \quad (\because K_a = 1.4 \times 10^{-3})$$

$$= 0.0655$$

Again,



$$\text{Total moles of equilibrium} = 1 - \alpha + \alpha + \alpha$$

$$= 1 + \alpha$$

$$\text{Therefore, } i = \frac{1 + \alpha}{1}$$

$$= 1 + \alpha$$

$$= 1 + 0.0655$$

$$= 1.0655$$

Hence, the depression in the freezing point of water is given as:

$$\Delta T_f = i \cdot K_f \cdot m$$

$$= 1.0655 \times 1.86 \text{ K kg mol}^{-1} \times 0.3264 \text{ mol kg}^{-1}$$

$$= 0.65 \text{ K}$$

**29. 19.5 g of  $\text{CH}_2\text{FCOOH}$  is dissolved in 500 g of water. The depression in the freezing point of water observed is  $1.0^\circ\text{C}$ . Calculate the van't Hoff factor and dissociation constant of fluoroacetic acid.**

**Ans.** It is given that:

$$w_1 = 500 \text{ g}$$

$$w_2 = 19.5 \text{ g}$$

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

$$\Delta T_f = 1 \text{ K}$$

$$\text{We know that: } M_2 = \frac{K_f \times w_2 \times 1000}{\Delta T_f \times w_1}$$

$$= \frac{1.86 \text{ K kg mol}^{-1} \times 19.5 \text{ g} \times 1000 \text{ g kg}^{-1}}{500 \text{ g} \times 1 \text{ K}}$$

$$72.54 \text{ g mol}^{-1}$$

Therefore, observed molar mass of  $\text{CH}_2\text{FCOOH}$ ,  $(M_2)_{\text{obs}} = 72.54 \text{ g mol}^{-1}$

The calculated molar mass of  $\text{CH}_2\text{FCOOH}$  is:

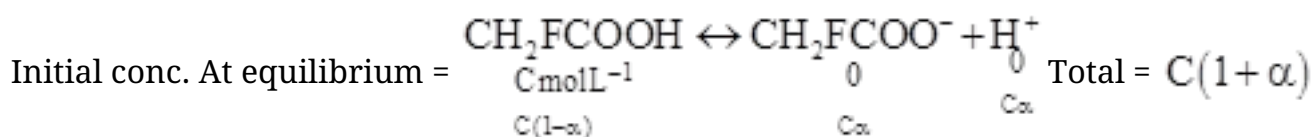
$$\begin{aligned}(M_2)_{\text{cal}} &= 14 + 19 + 12 + 16 + 16 + 1 \\ &= 78 \text{ g mol}^{-1}\end{aligned}$$

Therefore, van't Hoff factor,  $i = \frac{(M_2)_{\text{cal}}}{(M_2)_{\text{obs}}}$

$$\frac{78 \text{ g mol}^{-1}}{72.54 \text{ g mol}^{-1}}$$

$$= 1.0753$$

Let  $\alpha$  be the degree of dissociation of  $\text{CH}_2\text{FCOOH}$



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

$$i = 1 + \alpha$$

$$\alpha = i - 1$$

$$= 1.0753 - 1$$

$$= 0.0753$$

Now, the value of  $K_a$  is given as:

$$K_a = \frac{[\text{CH}_2\text{FCOO}^-][\text{H}^+]}{[\text{CH}_2\text{FCOOH}]}$$

$$= \frac{C\alpha \cdot C\alpha}{C(1-\alpha)}$$

$$\frac{C\alpha^2}{1-\alpha}$$

Taking the volume of the solution as 500 mL, we have the concentration:

$$C = \frac{19.5}{\frac{78}{500}} \times 1000M$$

$$= 0.5 M$$

$$\text{Therefore, } K_s = \frac{C\alpha^2}{1-\alpha}$$

$$= \frac{0.5 \times (0.0753)^2}{1-0.0753}$$

$$= \frac{0.5 \times 0.00567}{0.9247}$$

$$= 0.00307 \text{ (approximately)}$$

$$= 3.07 \times 10^{-3}$$

**30. Vapour pressure of water at 293 K is 17.535 mm Hg. Calculate the vapour pressure of water at 293 K when 25 g of glucose is dissolved in 450 g of water.**

**Ans.** Vapour pressure of water,  $p_1^0 = 17.535$  mm of Hg

Mass of glucose,  $w_2 = 25$  g

Mass of water,  $w_1 = 450$  g

We know that,

Molar mass of glucose ( $C_6H_{12}O_6$ ),  $M_2 = 6 \times 12 + 12 \times 1 + 6 \times 16$

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

Molar mass of water,  $M_1 = 18 \text{ g mol}^{-1}$

$$\text{Then, number of moles of glucose, } n_2 = \frac{25}{180 \text{ g mol}^{-1}}$$

$$= 0.139 \text{ mol}$$

$$\text{And, number of moles of water, } n_1 = \frac{450}{18 \text{ g mol}^{-1}}$$

$$= 25 \text{ mol}$$

We know that,

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

$$\frac{17.535 - p_1}{17.535} = \frac{0.139}{0.139 + 25}$$

$$17.535 - p_1 = \frac{0.139 \times 17.535}{25.139}$$

$$17.535 - p_1 = 0.097$$

$$p_1 = 17.44 \text{ mm of Hg}$$

Hence, the vapour pressure of water is 17.44 mm of Hg.

**31. 100 g of liquid A (molar mass  $140 \text{ g mol}^{-1}$ ) was dissolved in 1000 g of liquid B (molar mass  $180 \text{ g mol}^{-1}$ ). The vapour pressure of pure liquid B was found to be 500 torr.**

**Calculate the vapour pressure of pure liquid A and its vapour pressure in the solution if the total vapour pressure of the solution is 475 Torr.**

**Ans.** Number of moles of liquid A,  $n_A = \frac{100}{140} \text{ mol}$

= 0.714 mol

Number of moles of liquid B,  $n_B = \frac{1000}{180} \text{ mol}$

= 5.556 mol

Then, mole fraction of A,  $x_A = \frac{n_A}{n_A + n_B}$

$$= \frac{0.714}{0.714 + 5.556}$$

= 0.114

And, mole fraction of B,  $x_B = 1 - 0.114$

= 0.886

Vapour pressure of pure liquid B,  $p_1^0 = 500 \text{ torr}$

Therefore, vapour pressure of liquid B in the solution,

$$p_B = p_B^0 x_B$$

$$= 500 \times 0.886$$

= 443 torr

Total vapour pressure of the solution,  $p_{\text{total}} = 475 \text{ torr}$

Therefore, Vapour pressure of liquid A in the solution,

$$p_A = p_{\text{total}} - p_B$$

= 475 - 443

= 32 torr

$$P_A = P_A^0 x_A$$

$$\text{Now, } P_A^0 = \frac{P_A}{x_A}$$

$$= \frac{32}{0.114}$$

= 280.7 torr

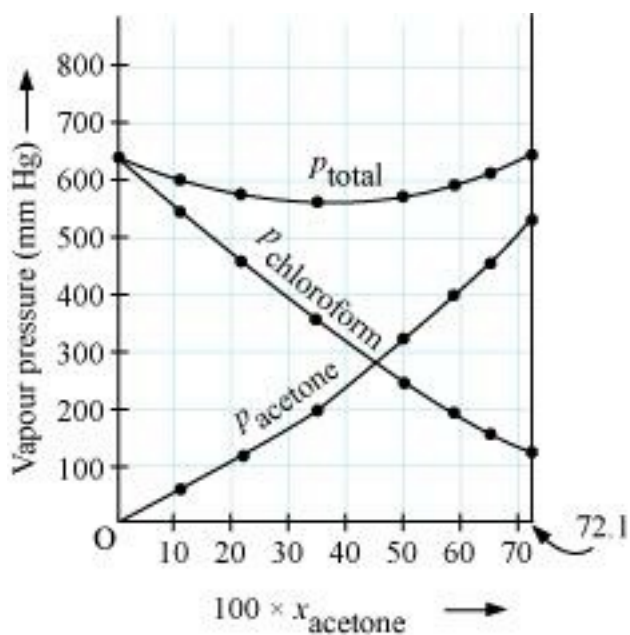
Hence, the vapour pressure of pure liquid A is 280.7 torr.

**32. Vapor pressure of pure acetone and chloroform at 328 K are 741.8 mm Hg and 632.8 mm Hg respectively. Assuming that they form ideal solution over the entire range of composition, plot  $p$  total'  $p$  chloroform' and  $p$  acetone as a function of  $x$  acetone. The experimental data observed for different compositions of mixture is.**

|                      |       |       |       |       |       |       |       |       |
|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| 100× x acetones      | 0     | 11.8  | 23.4  | 36.0  | 50.8  | 58.2  | 64.5  | 72.1  |
| acetone /mm Hg       | 0     | 54.9  | 110.1 | 202.4 | 322.7 | 405.9 | 454.1 | 521.1 |
| $p$ chloroform/mm Hg | 632.8 | 548.1 | 469.4 | 359.7 | 257.7 | 193.6 | 161.2 | 120.7 |

Ans. From the question, we have the following data

|                      |       |       |       |       |       |       |       |       |
|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| 100× x acetones      | 0     | 11.8  | 23.4  | 36.0  | 50.8  | 58.2  | 64.5  | 72.1  |
| $p$ acetone/mm Hg    | 0     | 54.9  | 110.1 | 202.4 | 322.7 | 405.9 | 454.1 | 521.1 |
| $P$ chloroform/mm Hg | 632.8 | 548.1 | 469.4 | 359.7 | 257.7 | 193.6 | 161.2 | 120.7 |
| $p$ tota(mm Hg)      | 632.8 | 603.0 | 579.5 | 562.1 | 580.4 | 599.5 | 615.3 | 641.8 |



It can be observed from the graph that the plot for the  $p_{\text{total}}$  of the solution curves downwards. Therefore, the solution shows negative deviation from the ideal behaviour.

**33. 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.**

Ans. Molar mass of benzene ( $\text{C}_6\text{H}_6$ ) =  $6 \times 12 + 6 \times 1$

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

Molar mass of toluene ( $\text{C}_6\text{H}_5\text{CH}_3$ ) =  $7 \times 12 + 8 \times 1$

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

Now, no. of moles present in 80 g of benzene =  $\frac{80}{78} \text{ mol}$

$$= 1.026 \text{ mol}$$

And, no. of moles present in 100 g of toluene =  $\frac{100}{92} \text{ mol}$



=1.087 mol

Therefore, Mole fraction of benzene,  $x_b = \frac{1.026}{1.025 + 1.087}$

= 0.486

And, mole fraction of toluene,  $x_t = 1 - 0.486$

= 0.514

It is given that vapour pressure of pure benzene,  $p_b^0 = 50.71 \text{ mm Hg}$

And, vapour pressure of pure toluene,  $p_t^0 = 32.06 \text{ mm HG}$

Therefore, partial vapour pressure of benzene,  $p_b = x_b \times p_b^0$

=  $0.486 \times 50.71$

= 24.645 mm Hg

And, partial vapour pressure of toluene,  $p_t = x_t \times p_t^0$

=  $0.514 \times 32.06$

= 16.479 mm Hg

Hence, mole fraction of benzene in vapour phase is given by:

$$\frac{p_b}{p_b + p_t}$$
$$= \frac{24.645}{24.645 + 16.479}$$

$$= \frac{24.645}{41.124}$$

= 0.599

= 0.6

**34. 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  $3.30 \times 10^7$  mm and  $6.51 \times 10^7$  mm respectively, calculate the composition of these gases in water.**

**Ans.** Percentage of oxygen ( $O_2$ ) in air = 20 %

Percentage of nitrogen ( $N_2$ ) in air = 79%

Also, it is given that water is in equilibrium with air at a total pressure of 10 atm, that is,  
( $10 \times 760$ ) mm Hg = 7600 mm Hg

Therefore,

$$\text{Partial pressure of oxygen, } p_{O_2} = \frac{20}{100} \times 7600 \text{ mm Hg}$$

$$= 1520 \text{ mm Hg}$$

$$\text{Partial pressure of nitrogen, } p_{N_2} = \frac{79}{100} \times 7600 \text{ mm Hg}$$

$$= 6004 \text{ mmHg}$$

Now, according to Henry's law:

$$p = K_H \cdot x \text{ For oxygen:}$$

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

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

$$= \frac{1520 \text{ mm Hg}}{3.30 \times 10^7 \text{ mm Hg}} \text{ (Given } K_H = 3.30 \times 10^7 \text{ mm Hg)}$$

$$= 4.61 \times 10^{-5}$$

For nitrogen:

$$p_{N_2} = K_H \cdot x_{N_2}$$

$$x_{N_2} = \frac{p_{N_2}}{K_H}$$

$$= \frac{6004 \text{ mm Hg}}{6.51 \times 10^7 \text{ mm Hg}}$$

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

Hence, the mole fractions of oxygen and nitrogen in water are  $4.61 \times 10^{-5}$  and  $9.22 \times 10^{-5}$  respectively.

**35. Determine the amount of  $\text{CaCl}_2$  ( $i = 2.47$ ) dissolved in 2.5 litre of water such that its osmotic pressure is 0.75 atm at  $27^\circ\text{C}$ .**

**Ans.** We know that,

$$\pi = i \frac{n}{V} RT$$

$$\pi = i \frac{w}{MV} RT$$

$$w = \frac{\pi MV}{iRT}$$

$$\pi = 0.75 \text{ atm}$$

$$V = 2.5 \text{ L}$$

$$i = 2.47$$

$$T = (27 + 273)K = 300 K$$

Here,

$$R = 0.0821 \text{ L atm K}^{-1}\text{mol}^{-1}$$

$$M = 1 \times 40 + 2 \times 35.5$$

$$= 111 \text{ g mol}^{-1}$$

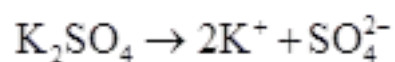
$$\text{Therefore, } w = \frac{0.75 \times 111 \times 2.5}{2.47 \times 0.0821 \times 300}$$

$$= 3.42 \text{ g}$$

Hence, the required amount of  $\text{CaCl}_2$  is 3.42 g.

**36. Determine the osmotic pressure of a solution prepared by dissolving 25 mg of  $\text{K}_2\text{SO}_4$  in 2 liter of water at  $25^\circ\text{C}$ , assuming that it is completely dissociated.**

**Ans.** When  $\text{K}_2\text{SO}_4$  is dissolved in water,  $\text{K}^+$  and  $\text{SO}_4^{2-}$  ions are produced.



Total number of ions produced = 3

Therefore,  $i = 3$

Given,

$$w = 25 \text{ mg} = 0.025 \text{ g}$$

$$V = 2 \text{ L}$$

$$T = 25^\circ\text{C} = (25 + 273) \text{ K} = 298 \text{ K}$$

Also, we know that:

$$R = 0.0821 \text{ L atm K}^{-1}\text{mol}^{-1}$$

$$M = (2 \times 39) + (1 \times 32) + (4 \times 16) = 174 \text{ g mol}^{-1}$$

Applying the following relation,

$$\pi = i \frac{n}{v} RT$$

$$= i \frac{w}{M} \frac{1}{v} RT$$

$$= 3 \times \frac{0.025}{174} \times \frac{1}{2} \times 0.0821 \times 298$$

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

