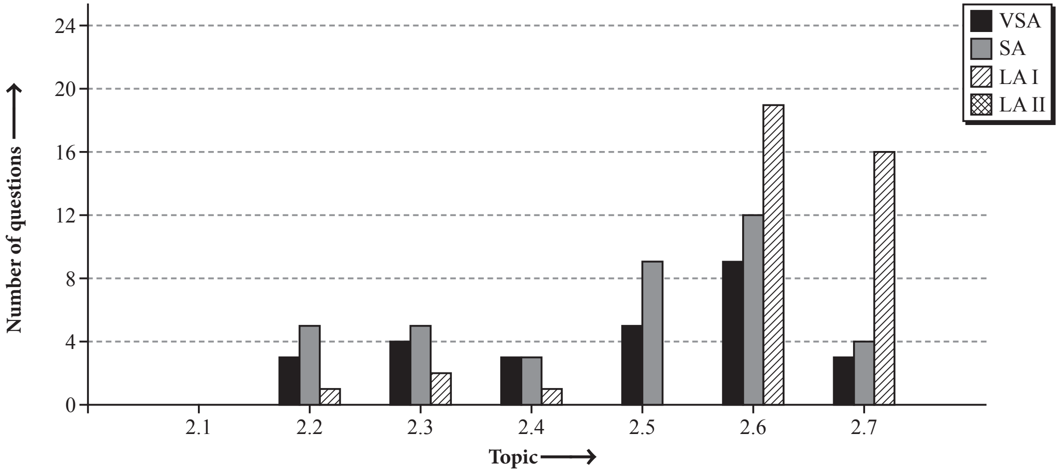
CHAPTER

2

Solutions

Topicwise Analysis of Last 10 Years' CBSE Board Questions (2020-2011)



- Maximum total weightage is of *Colligative Properties and Determination of Molar Mass.*
- Maximum VSA type questions were asked from *Colligative Properties and Determination of Molar Mass.*
- Maximum SA type questions were asked from *Ideal and Non-Ideal Solutions* and *Colligative Properties and Determination of Molar Mass.*
- Maximum LA I type questions were asked from *Colligative Properties and Determination of Molar Mass.*

QUICK RECAP

- **Solution :** A perfectly homogeneous mixture of two or more components is called *solution*.
- **Solute :** The component which is present in lesser amount or whose physical state is changed during the formation of solution is called *solute*.

- **Solvent :** The component which is present in larger amount and determines the physical state of the solution is called *solvent*.
- **Types of solution :** Depending upon the nature of solute and solvent, solutions are classified as follows :
  - **Gaseous solutions :** Solutions in which gas acts as solvent.

Solute	Solvent	Examples
Solid	Gas	Iodine vapours in air, dust or smoke particles in air
Liquid	Gas	Water vapours in air (humidity)
Gas	Gas	Air

  - **Liquid solutions :** Solutions in which liquids are present in larger amount.

Solute	Solvent	Examples
Solid	Liquid	Salt/sugar in water
Liquid	Liquid	Alcohol in water
Gas	Liquid	Aerated drinks, O_2 in water

  - **Solid solutions :** Solutions in which solids are present in larger amount.

Solute	Solvent	Examples
Solid	Solid	Alloys
Liquid	Solid	Hg in Ag, Hg in Zn (Amalgam)
Gas	Solid	Solution of hydrogen in palladium.

- **Different methods for expressing concentration of solution :**

Method of expressing	Formula
Mass percentage	$\left(\frac{w}{W}\right)\% = \frac{w_2}{(w_1 + w_2)} \times 100$
Volume percentage	$\left(\frac{v}{V}\right)\% = \frac{V_2}{(V_1 + V_2)} \times 100$
Mass by volume percentage	$\left(\frac{w}{V}\right)\% = \frac{w_2}{V_{\text{solution}}\,(\text{in mL})} \times 100$
Mass fraction	$x_1 = \frac{w_1}{w_1 + w_2}$ or $x_2 = \frac{w_2}{w_1 + w_2}$
Strength ($g\ L^{-1}$)	$\frac{w_2\ (\text{in g})}{V_{\text{solution}}\ (\text{in mL})} \times 1000$
Parts per million (ppm)	$\frac{w_2}{(w_1 + w_2)} \times 10^6$
Molarity, (M) (mol L^{-1})	$\frac{w_2 \times 1000}{M_2 \times V_{\text{solution}}\,(\text{in mL})}$
Molality, (m) (mol kg^{-1})	$\frac{w_2 \times 1000}{M_2 \times w_1\,(\text{in g})}$
Mole fraction, (x)	$x_1 = \frac{n_1}{n_1 + n_2}$ or $x_2 = \frac{n_2}{n_1 + n_2}$ ($x_1 + x_2 = 1$) In case of gases only, $y_1 = \frac{p_1}{p_1 + p_2}$ or $y_2 = \frac{p_2}{p_1 + p_2}$ ($y_1 + y_2 = 1$)

- **Solubility :** Maximum amount of substance that can be dissolved in a specified amount of solvent at a specified temperature is called its *solubility*.
- **Factors affecting solubility of a solid in a liquid :**
  - **Nature of solute and solvent :** Polar solutes dissolve in polar solvents and non-polar solutes dissolve in non-polar solvents. (*i.e.*, like dissolves like).
  - **Effect of temperature :**
    - If the dissolution process is endothermic ($\Delta_{sol}H > 0$), the solubility **increases** with **rise** in temperature.
    - If dissolution process is exothermic ($\Delta_{sol}H < 0$), the solubility **decreases** with **rise** in temperature.
  - **Effect of pressure :** Pressure does not have any significant effect on solubility of solids in liquids as these are highly incompressible.

- **Factors affecting solubility of a gas in a liquid:**
  - **Effect of pressure : Henry's law** states that "the partial pressure of the gas in vapour phase (p) is proportional to the mole fraction of the gas (x) in the solution"
    $p = K_H x$ where, K_H is the Henry's law constant and is different for different gases at a particular temperature.
    Higher the value of K_H at a given pressure, the lower is the solubility of the gas in the liquid.
  - **Effect of temperature :** As dissolution is an exothermic process, then according to Le Chatelier's principle, the solubility should decrease with increase of temperature.

- **Raoult's law :** It states that for a solution of volatile liquids, the partial vapour pressure of each component of the solution is directly proportional to its mole fraction present in solution. $p_1 = p_1^\circ x_1$ and $p_2 = p_2^\circ x_2$; where p_1° and p_2° are vapour pressures of pure components 1 and 2 respectively, at the same temperature.

- **Dalton's law of partial pressures :**

$$P_{\text{total}} = p_1 + p_2 = x_1 p_1^\circ + x_2 p_2^\circ$$
$$= (1 - x_2)p_1^\circ + x_2 p_2^\circ = p_1^\circ + (p_2^\circ - p_1^\circ) x_2$$

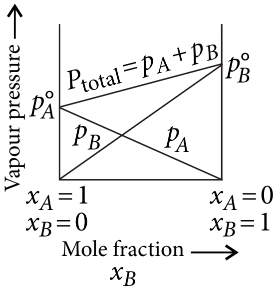
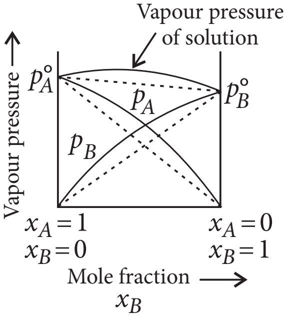
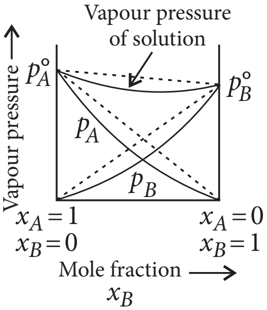
- If y_1 and y_2 are the mole fractions of the components 1 and 2 respectively in the vapour phase then, $p_1 = y_1 P_{\text{total}}$ and $p_2 = y_2 P_{\text{total}}$

- **Raoult's law for solid-liquid solutions :** It states that relative lowering in vapour pressure of a solution containing a non-volatile solute is equal to the mole fraction of the solute.

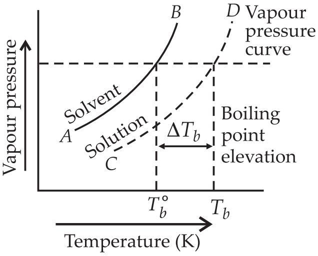
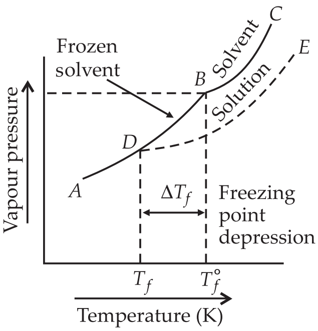
$$\frac{p^\circ - p_s}{p^\circ} = x_2$$

where, p° = vapour pressure of pure solvent
p_s = vapour pressure of solution
x_2 = mole fraction of solute.

- **Ideal and non-ideal solutions :**

Ideal solutions	**Non-ideal solutions**	
	Positive deviation from Raoult's law	**Negative deviation from Raoult's law**
		
$A - B$ interactions ≈ $A - A$ and $B - B$ interactions	$A - B$ interactions << $A - A$ and $B - B$ interactions	$A - B$ interactions >> $A - A$ and $B - B$ interactions
$\Delta H_{\text{mix}} = 0$, $\Delta V_{\text{mix}} = 0$	$\Delta H_{\text{mix}} > 0$, $\Delta V_{\text{mix}} > 0$	$\Delta H_{\text{mix}} < 0$, $\Delta V_{\text{mix}} < 0$
e.g., dilute solutions, benzene + toluene, *n*-hexane + *n*-heptane	*e.g.*, acetone + ethanol, acetone + CS_2, water + methanol	*e.g.*, acetone + aniline, acetone + chloroform, HNO_3 + water

- **Azeotropes :** The mixtures of liquids which boil at constant temperature like a pure liquid and possess same composition of components in liquid as well as vapour phase are called *constant boiling mixtures* or *azeotropic mixtures*.
  - **Minimum boiling azeotropes :** They formed by those liquid pairs which show positive deviations from ideal behaviour *e.g.*, ethanol-water mixture.
  - **Maximum boiling azeotropes :** They are formed by those liquid pairs which show negative deviations from ideal behaviour, *e.g.*, nitric acid-water mixture.
- **Colligative properties :** Properties which depend only on the number of solute particles dissolved in a definite amount of the solvent and do not depend on the nature of the solute are called *colligative properties*.

Colligative properties	Expression
Relative lowering of vapour pressure : When a non-volatile solute is dissolved in a solvent, vapour pressure of the solution is lower than that of the pure solvent which is known as *lowering of vapour pressure*. Relative lowering of vapour pressure is equal to the mole fraction of the solute in the solution.	$\frac{p_1^\circ - p_1}{p_1^\circ} = x_2 = \frac{n_2}{n_1 + n_2}$ $= \frac{n_2}{n_1} = \frac{w_2 \times M_1}{M_2 \times w_1}$ ($\because$ for dilute solutions, $n_2 << n_1$)
Elevation in boiling point : The boiling point of a solution containing a non-volatile solute is always higher than the boiling point of the pure solvent. This increase in boiling point is termed as *elevation in boiling point*.  	$\Delta T_b = T_b - T_b^\circ$ $\Delta T_b \propto m$ or $\Delta T_b = K_b m$ $= K_b \left(\frac{w_2 \times 1000}{M_2 \times w_1 (\text{in g})}\right)$ or $M_2 = \frac{K_b \times w_2 \times 1000}{\Delta T_b \times w_1 (\text{in g})}$ K_b is called *boiling point elevation constant* or *molal elevation constant* or *ebullioscopic constant*, having unit K kg mol^{-1}.
Depression in freezing point : The freezing point of a solution containing a non-volatile solute is always less than the freezing point of the pure solvent. This decrease in freezing point is termed as *depression in freezing point*.  	$\Delta T_f = T_f^\circ - T_f$ $\Delta T_f \propto m$ or $\Delta T_f = K_f m$ $= K_f \left(\frac{w_2 \times 1000}{M_2 \times w_1 (\text{in g})}\right)$ or $M_2 = \frac{K_f \times w_2 \times 1000}{\Delta T_f \times w_1 (\text{in g})}$ K_f is known as *freezing point depression constant* or *molal depression constant* or *cryoscopic constant*, having unit K kg mol^{-1}.
Osmotic pressure : The movement of solvent molecules from less concentrated solution to more concentrated solution through semipermeable membrane is termed as *osmosis*. The hydrostatic pressure which develops on account of osmosis is called *osmotic pressure* or the excess pressure that must be applied on the solution to prevent osmosis is called *osmotic pressure*.	$\pi = CRT = \left(\frac{n_2}{V}\right)RT$, $\pi V = \frac{w_2 RT}{M_2}$ or $M_2 = \frac{w_2 RT}{\pi V}$

- Two solutions having same osmotic pressure at a given temperature are called *isotonic solutions*.
- If one solution is of lower osmotic pressure, it is called *hypotonic* with respect to the more concentrated solution. The more concentrated solution is said to be *hypertonic* with respect to the dilute solution.
- If a pressure higher than the osmotic pressure is applied on the solution, the solvent will flow from the solution into the pure solvent through the semipermeable membrane and the process is called *reverse osmosis*. It is used in *desalination of sea water*.

Abnormal molecular mass : When the molecular mass of a substance determined by any of the colligative properties comes out to be different than the expected value, the substance is said to show *abnormal molecular mass*.

- Abnormal molecular masses are observed when the solution is non-ideal (not dilute) or the solute undergoes *association* or *dissociation*.

van't Hoff Factor : It is defined as the ratio of the experimental value of the colligative property to the calculated value of the colligative property.

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

$$i = \frac{\text{Calculated molecular mass}}{\text{Observed molecular mass}}$$

$$i = \frac{\begin{array}{c}\text{(Total number of moles of particles}\\ \text{after association / dissociation)}\end{array}}{\begin{array}{c}\text{(Total number of moles of particles}\\ \text{before association / dissociation)}\end{array}}$$

- If $i > 1$, solute undergoes dissociation in the solution and if $i < 1$, solute undergoes association in the solution.

$$\alpha_{\text{dissociation}} = \frac{i-1}{n-1}$$

$$\alpha_{\text{association}} = \frac{1-i}{1-\frac{1}{n}}$$

- For substances undergoing association or dissociation in the solution, the various expressions for the colligative properties are modified as follows :

$$\frac{p_1^\circ - p_1}{p_1^\circ} = ix_2 ; \Delta T_b = iK_b m;$$

$$\Delta T_f = iK_f m;$$

$$\pi = iCRT$$

Previous Years' CBSE Board Questions

2.2 Expressing Concentration of Solutions

VSA **(1 mark)**

1. Define the following term :
Molality (m) *(1/2, Delhi 2017, 1/5 AI 2014C)*

2. Define the following term:
Molarity (M) *(1/2, Delhi 2017, 1/5 AI 2014)*

3. Define the following term :
Mole fraction
(1/5 AI 2014 C, 1/2, Delhi 2012, AI 2012)

SA **(2 marks)**

4. Calculate the molarity of 9.8% (w/W) solution of H_2SO_4 if the density of the solution is 1.02 g mL^{-1}. (Molar mass of H_2SO_4 = 98 g mol^{-1}) *(2/5, Foreign 2014)*

5. Differentiate between molarity and molality of a solution. How can we change molality value of a solution into molarity value? *(Delhi 2014C)*

6. A solution of glucose ($C_6H_{12}O_6$) in water is labelled as 10% by weight. What would be the molality of the solution?
(Molar mass of glucose = 180 g mol^{-1})
(2/5, AI 2013)

7. Differentiate between molarity and molality in a solution. What is the effect of temperature change on molarity and molality in a solution? *(2/5, Delhi 2011, 2/5, AI 2011)*

8. Differentiate between molarity and molality of a solution. Explain how molarity value of a solution can be converted into its molality? *(Foreign 2011)*

LA I **(3 marks)**

9. A solution of glucose (molar mass = 180 g mol^{-1}) in water is labelled as 10% (by mass). What would be the molality and molarity of the solution? (Density of solution = 1.2 g mL^{-1}) *(3/5, AI 2014)*

2.3 Solubility

VSA **(1 mark)**

10. Why aquatic animals are more comfortable in cold water than in warm water? *(1/3, 2018)*

11. Gas (A) is more soluble in water than gas (B) at the same temperature. Which one of the two gases will have the higher value of K_H (Henry's constant) and why? *(1/2, AI 2016)*

12. Explain the following :
Henry's law about dissolution of a gas in a liquid. *(1/5, AI 2012)*

13. State the following :
Henry's law about partial pressure of a gas in a mixture. *(1/5, Delhi, AI 2011)*

SA **(2 marks)**

14. State Henry's law. Why is air diluted with helium in the tanks used by scuba divers? *(2/5, 2020)*

15. State Henry's law. Calculate the solubility of CO_2 in water at 298 K under 760 mm Hg. (K_H for CO_2 in water at 298 K is 1.25×10^6 mm Hg) *(2020)*

16. Give reasons for the following.
   (a) Aquatic species are more comfortable in cold water than in warm water.
   (b) At higher altitudes people suffer from anoxia resulting in inability to think. *(AI 2019)*

17. State Henry's law and mention two of its important applications.
(2/5, AI 2013C, 2012C)

18. Explain why aquatic species are more comfortable in cold water rather than in warm water. *(Delhi 2012C)*

LA I **(3 marks)**

19. The partial pressure of ethane over a saturated solution containing 6.56×10^{-2} g of ethane is 1 bar. If the solution contains 5.0×10^{-2} g of ethane, then what will be the partial pressure of the gas?
(Delhi 2013C, AI 2012C)

20. If N_2 gas is bubbled through water at 293 K, how many millimoles of N_2 gas would dissolve in 1 litre of water? Assume that N_2 exerts a partial pressure of 0.987 bar. Given that Henry's law constant for N_2 at 293 K is 76.48 kbar. *(AI 2012C)*

2.4 Vapour Pressure of Liquid Solutions

VSA **(1 mark)**

21. Identify which liquid will have a higher vapour pressure at 90°C if the boiling points of two liquids *A* and *B* are 140°C and 180°C, respectively. *(One word, 2020)*

22. Define Raoult's law. *(1/5 AI 2014C)*

23. State the following :
Raoult's law in its general form in reference to solutions. *(1/5, Delhi, 1/2, AI 2011)*

SA **(2 marks)**

24. State Raoult's law for the solution containing volatile components. What is the similarity between Raoult's law and Henry's law? *(Delhi 2014, AI 2013)*

25. State Raoult's law for a solution containing volatile components. Name the solution which follows Raoult's law at all concentrations and temperatures. *(2/5, Foreign 2014)*

26. State Raoult's law. How is it formulated for solutions of non-volatile solutes? *(Delhi 2012C)*

LA I **(3 marks)**

27. 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. *(3/5, AI 2013C)*

2.5 Ideal and Non-ideal Solutions

VSA **(1 mark)**

28. What happens when acetone is added to pure ethanol? *(1/2, 2020)*

29. Define the following term :
Ideal solution
(1/2, Delhi 2017, 1/5, AI 2017C, 1/5, AI 2013, 2012, 1/2, Delhi 2012)

30. In non-ideal solution, what type of deviation shows the formation of maximum boiling azeotropes? *(1/2, AI 2016)*

31. Some liquids on mixing form 'azeotropes'. What are 'azeotropes'? *(Delhi 2014)*

32. Define the following term :
Azeotrope *(1/5, Foreign 2014)*

SA **(2 marks)**

33. Write two differences between ideal solutions and non-ideal solutions. *(Delhi 2019, 2/5, AI 2017)*

34. What type of azeotropic mixture will be formed by a solution of acetone and chloroform? Justify on the basis of strength of intermolecular interactions that develop in the solution. *(AI 2019)*

35. What is meant by positive deviations from Raoult's law? Give an example. What is the sign of $\Delta_{mix}H$ for positive deviation? *(Delhi 2015)*

36. Define azeotropes. What type of azeotrope is formed by positive deviation from Raoult's law? Give an example. *(Delhi 2015)*

37. What is meant by negative deviation from Raoult's law? Give an example. What is the sign of $\Delta_{mix}H$ for negative deviation? *(Foreign 2015)*

38. Define azeotropes. What type of azeotrope is formed by negative deviation from Raoult's law? Give an example. *(Foreign 2015)*

39. What type of deviation is shown by a mixture of ethanol and acetone? Give reason. *(2/5, AI 2014)*

40. What is meant by positive and negative deviations from Raoult's law and how is the sign of $\Delta_{mix}H$ related to positive and negative deviations from Raoult's law? *(AI 2013 C)*

41. Explain why a solution of chloroform and acetone shows negative deviation from Raoult's law. *(2/5, Delhi 2011C)*

2.6 Colligative Properties and Determination of Molar Mass

VSA (1 mark)

42. **Assertion (A) :** Osmotic pressure is a colligative property.
Reason (R) : Osmotic pressure is directly proportional to molarity.
(a) Both Assertion (A) and Reason (R) are correct statements, and Reason (R) is the correct explanation of the Assertion (A).
(b) Both Assertion (A) and Reason (R) are correct statements, but Reason (R) is not the correct explanation of the Assertion (A).
(c) Assertion (A) is correct, but Reason (R) is incorrect statement.
(d) Assertion (A) is incorrect, but Reason (R) is correct statement. *(2020)*

43. What happens when a pressure greater than osmotic pressure is applied on the solution side separated from solvent by a semi-permeable membrane? *(1/2, 2020)*

44. Give reason for the following :
Measurement of osmotic pressure method is preferred for the determination of molar masses of macromolecules such as proteins and polymers. *(1/2, 2018)*

45. Define the following term :
Colligative properties *(1/2, Delhi 2017)*

46. Define the following term :
Osmotic pressure *(1/5, AI 2017C, 2013)*

47. What are isotonic solutions?
(Delhi 2014; 1/2, Delhi 2012)

48. Define the following term :
Molal elevation constant (K_b) *(1/5, AI 2014)*

49. How is the vapour pressure of a solvent affected when a non-volatile solute is dissolved in it? *(1/2, Delhi 2014C)*

50. Explain the following :
Boiling point elevation constant for a solvent. *(AI 2012)*

SA (2 marks)

51. For a 5% solution of urea (Molar mass = 60 g/mol), calculate the osmotic pressure at 300 K.[$R = 0.0821$ L atm K^{-1} mol^{-1}] *(2020)*

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

53. Give reasons :
(i) 0.1 M KCl has higher boiling point than 0.1 M glucose.
(ii) Meat is preserved for a longer time by salting. *(2020)*

54. Calculate the freezing point of a solution containing 60 g of glucose (molar mass = 180 g mol^{-1}) in 250 g of water.
(K_f of water = 1.86 K kg mol^{-1}) *(2018)*

55. (i) Out of 1 M glucose and 2 M glucose, which one has a higher boiling point and why?
(ii) What happens when the external pressure applied becomes more than the osmotic pressure of solution?
(2/5, Delhi 2016)

56. Blood cells are isotonic with 0.9% sodium chloride solution. What happens if we place blood cells in a solution containing
(i) 1.2% sodium chloride solution?
(ii) 0.4% sodium chloride solution?
(2/5, Delhi 2016)

57. Why does a solution containing non-volatile solute have higher boiling point than the pure solvent? Why is elevation of boiling point a colligative property? *(AI 2015)*

58. Calculate the mass of compound (molar mass = 256 g mol^{-1}) to be dissolved in 75 g of benzene to lower its freezing point by 0.48 K. (K_f = 5.12 K kg mol^{-1}). *(Delhi 2014)*

59. 18 g of glucose, $C_6H_{12}O_6$ (Molar mass = 180 g mol^{-1}) is dissolved in 1 kg of water in a sauce pan. At what temperature will this solution boil?
(K_b for water = 0.52 K kg mol^{-1}, boiling point of pure water = 373. 15 K) *(Delhi 2013)*

60. An aqueous solution of sodium chloride freezes below 273 K. Explain the lowering in freezing point of water with the help of a suitable diagram. *(Delhi 2013C)*

61. Define the terms osmosis and osmotic pressure. Is the osmotic pressure of a solution a colligative property? Explain. *(2/5, Delhi 2011)*

62. List any four factors on which the colligative properties of a solution depend. *(2/5, AI 2011C)*

LA I (3 marks)

63. Calculate the mass of ascorbic acid (Molar mass = 176 g mol^{-1}) to be dissolved in 75 g of acetic acid, to lower its freezing point by 1.5°C .
(K_f = 3.9 K kg mol^{-1}) *(2020)*

64. A 4% solution (*w*/*w*) of sucrose (M = 342 g mol^{-1}) in water has a freezing point of 271.15 K. Calculate the freezing point of 5% glucose (M = 180 g mol^{-1}) in water. (Given : Freezing point of pure water = 273.15 K) *(Delhi 2019)*

65. At 300 K, 30 g of glucose present in a litre of its solution has an osmotic pressure of 4.98 bar. If the osmotic pressure of a glucose solution is 1.52 bar at the same temperature, what would be its concentration? *(AI 2019)*

66. A 10% solution (by mass) of sucrose in water has freezing point of 269.15 K. Calculate the freezing point of 10% glucose in water, if freezing point of pure water is 273.15 K. (Given : Molar mass of sucrose = 342 g mol^{-1}, molar mass of glucose = 180 g mol^{-1}) *(Delhi 2017)*

67. 30 g of urea (M = 60 g mol^{-1}] is dissolved in 846 g of water. Calculate the vapour pressure of water for this solution if vapour pressure of pure water at 298 K is 23.8 mm Hg. *(3/5, AI 2017)*

68. Calculate the boiling point elevation for a solution prepared by adding 10 g of $CaCl_2$ to 200 g of water. (K_b for water = 0.52 K kg mol^{-1}, molar mass of $CaCl_2$ = 111 g mol^{-1}) *(3/5, AI 2017C, Foreign 2014)*

69. Calculate the freezing point of the solution when 31 g of ethylene glycol ($C_2H_6O_2$) is dissolved in 500 g of water.
(K_f for water = 1.86 K kg mol^{-1}) *(AI 2015)*

70. A solution containing 15 g urea (molar mass = 60 g mol^{-1}) per litre of solution in water has the same osmotic pressure (isotonic) as a solution of glucose (molar mass = 180 g mol^{-1}) in water. Calculate the mass of glucose present in one litre of its solution. *(3/5, AI 2014)*

71. Define the following terms :
(i) Osmotic pressure
(ii) Colligative properties *(Foreign 2014)*

72. Some ethylene glycol, $HOCH_2CH_2OH$, is added to your car's cooling system along with 5 kg of water. If the freezing point of water-glycol solution is –15.0°C, what is the boiling point of the solution?
(K_b = 0.52 K kg mol^{-1} and K_f = 1.86 K kg mol^{-1} for water) *(Delhi 2014C)*

73. 1.00 g of a non-electrolyte solute dissolved in 50 g of benzene lowered the freezing point of benzene by 0.40 K. The freezing point depression constant of benzene is 5.12 K kg mol^{-1}. Find the molar mass of the solute. *(AI 2013)*

74. A 5% solution (by mass) of cane-sugar in water has freezing point of 271 K. Calculate the freezing point of 5% solution (by mass) of glucose in water if the freezing point of pure water is 273.15 K.
[Molecular masses : Glucose $C_6H_{12}O_6$: 180 amu; Cane-sugar $C_{12}H_{22}O_{11}$: 342 amu] *(3/5, AI 2013C)*

75. A solution of glycerol ($C_3H_8O_3$) in water was prepared by dissolving some glycerol in 500 g of water. This solution has a boiling point of 100.42°C while pure water boils at 100°C. What mass of glycerol was dissolved to make the solution?
(K_b for water = 0.512 K kg mol^{-1}) *(Delhi 2012, AI 2012)*

76. 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 added to this solution. The new vapour pressure becomes 2.9 kPa at 298 K. Calculate

(i) the molecular mass of solute and

(ii) vapour pressure of water at 298 K.

(Delhi 2012C)

77. Calculate the boiling point of a solution prepared by adding 15.00 g of NaCl to 250.00 g of water. (K_b for water = 0.512 K kg mol^{-1}, Molar mass of NaCl = 58.44 g)

(3/5, Delhi 2011)

78. A solution prepared by dissolving 8.95 mg of a gene fragment in 35.0 mL of water has an osmotic pressure of 0.335 torr at 25°C. Assuming the gene fragment is a non-electrolyte, determine its molar mass.

(3/5, Delhi, AI 2011)

79. What would be the molar mass of a compound if 6.21 g of it dissolved in 24.0 g of chloroform to form a solution that has a boiling point of 68.04°C. The boiling point of pure chloroform is 61.7°C and the boiling point elevation constant, K_b for chloroform is 3.63°C/m. *(3/5, Delhi 2011)*

80. The molecular masses of polymers are determined by osmotic pressure method and not by measuring other colligative properties. Give two reasons.

(3/5, AI 2011C)

81. Calculate the boiling point of one molar aqueous solution (density 1.06 g mL^{-1}) of KBr. [Given : K_b for H_2O = 0.52 K kg mol^{-1}, atomic mass : K = 39, Br = 80]

(3/5, AI 2011C)

2.7 Abnormal Molar Masses

VSA (1 mark)

82 Give reason for the following :
Elevation of boiling point of 1 M KCl solution is nearly double than that of 1 M sugar solution. *(1/2, 2018)*

83. Define the following term :
van't Hoff factor

(Delhi 2017, 1/5, Delhi 2012)

84. Define the following term :
Abnormal molar mass *(Delhi 2017)*

SA (2 marks)

85. What is van't Hoff factor? What types of values can it have if in forming the solution the solute molecules undergo

(i) dissociation (ii) association?

(2/5, AI 2014C)

86. Assuming complete dissociation, calculate the expected freezing point of a solution prepared by dissolving 6.00 g of Glauber's salt, $Na_2SO_4 \cdot 10H_2O$ in 0.100 kg of water.

(K_f for water = 1.86 K kg mol^{-1}, atomic masses : Na = 23, S = 32, O = 16, H = 1)

(2/5, AI 2014C)

87. A 1.00 molal aqueous solution of trichloroacetic acid (CCl_3COOH) is heated to its boiling point. The solution has the boiling point of 100.18°C. Determine the van't Hoff factor for trichloroacetic acid. (K_b for water = 0.512 K kg mol^{-1})

(Delhi 2012)

88. What is van't Hoff factor? What possible value can it have if the solute molecules undergo dissociation? *(2/5, Delhi 2011C)*

LA I (3 marks)

89. A solution contains 5.85 g NaCl (Molar mass = 58.5 g mol^{-1}) per litre of solution. It has an osmotic pressure of 4.75 atm at 27°C. Calculate the degree of dissociation of NaCl in this solution.
(Given : R = 0.082 L atm K^{-1} mol^{-1})

(3/5, 2020)

90. When 19.5 g of $F{-}CH_2{-}COOH$ (molar mass = 78 g mol^{-1}) is dissolved in 500 g of water, the depression in freezing point is observed to be 1°C. Calculate the degree of dissociation of $F{-}CH_2{-}COOH$.
[Given : K_f for water = 1.86 K kg mol^{-1}]

(3/5, 2020)

91. The freezing point of a solution containing 5 g of benzoic acid (M = 122 g mol^{-1}) in 35 g of benzene is depressed by 2.94 K. What is the percentage association of benzoic acid if it forms a dimer in solution?
(K_f for benzene = 4.9 K kg mol^{-1}) *(2020)*

92. Calculate the freezing point of solution when 1.9 g of $MgCl_2$(M = 95 g mol^{-1}) was dissolved in 50 g of water, assuming $MgCl_2$ undergoes complete ionization.
(K_f for water = 1.86 K kg mol^{-1})
(Delhi 2016)

93. When 2.56 g of sulphur was dissolved in 100 g of CS_2, the freezing point lowered by 0.383 K. Calculate the formula of sulphur (S_x).
(K_f the CS_2 = 3.83 K kg mol^{-1}, atomic mass of sulphur = 32 g mol^{-1}) *(3/5 Delhi 2016)*

94. Calculate the boiling point of solution when 4 g of $MgSO_4$ (M = 120 g mol^{-1}) was dissolved in 100 g of water, assuming $MgSO_4$ undergoes complete ionization.
(K_b for water = 0.52 K kg mol^{-1}) *(AI 2016)*

95. 3.9 g of benzoic acid dissolved in 49 g of benzene shows a depression in freezing point of 1.62 K. Calculate the van't Hoff factor and predict the nature of solute (associated or dissociated).
(Given : Molar mass of benzoic acid = 122 g mol^{-1}, K_f for benzene = 4.9 K kg mol^{-1})
(Delhi 2015)

96. Calculate the mass of NaCl (molar mass = 58.5 g mol^{-1}) to be dissolved in 37.2 g of water to lower the freezing point by 2°C, assuming that NaCl undergoes complete dissociation. (K_f for water = 1.86 K kg mol^{-1})
(Foreign 2015)

97. Determine the osmotic pressure of a solution prepared by dissolving 2.5×10^{-2} g of K_2SO_4 in 2 L of water at 25°C, assuming that it is completely dissociated.
(R = 0.0821 L atm K^{-1} mol^{-1}, molar mass of K_2SO_4 = 174 g mol^{-1}) *(Delhi 2013)*

98. Calculate the amount of KCl which must be added to 1 kg of water so that the freezing point is depressed by 2 K (the K_f for water = 1.86 K kg mol^{-1}). *(Delhi 2012)*

99. 15.0 g of an unknown molecular material was dissolved in 450 g of water. The resulting solution was found to freeze at –0.34°C. What is the molar mass of this material?
(K_f for water = 1.86 K kg mol^{-1})
(Delhi 2012, 3/5, AI 2012)

100. Calculate the freezing point of an aqueous solution containing 10.50 g of $MgBr_2$ in 200 g of water. (Molar mass of $MgBr_2$ = 184 g mol^{-1}, K_f for water = 1.86 K kg mol^{-1})
(3/5, Delhi 2011)

101. A 0.561 m solution of an unknown electrolyte depresses the freezing point of water by 2.93°C. What is van't Hoff factor for this electrolyte? The freezing point depression constant (K_f) for water is 1.86°C kg mol^{-1}.
(Foreign 2011)

102. Phenol associates in benzene to a certain extent to form a dimer. A solution containing 20 g of phenol in 1.0 kg of benzene has its freezing point lowered by 0.69 K. Calculate the fraction of phenol that has dimerised
[Given K_f for benzene = 5.1 K m^{-1}]
(3/5, Delhi 2011C)

103. An aqueous solution containing 12.48 g of barium chloride in 1.0 kg of water boils at 373.0832 K. Calculate the degree of dissociation of barium chloride.
[Given K_b for H_2O = 0.52 K m^{-1};
Molar mass of $BaCl_2$ = 208.34 g mol^{-1}]
(3/5, Delhi 2011C)

104. What mass of NaCl must be dissolved in 65.0 g of water to lower the freezing point of water by 7.50°C? The freezing point depression constant (K_f) for water is 1.86°C/m. Assume van't Hoff factor for NaCl is 1.87. (Molar mass of NaCl = 58.5 g mol^{-1})
(AI 2011)

Detailed Solutions

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

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

2. It is the number of moles of the solute dissolved per litre of the solution. It is denoted by M.

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

$$= \frac{n}{V(\text{in mL})} \times 1000 = \frac{w_2 \times 1000}{M_2 \times V(\text{in mL})}$$

$$\left(\therefore n_2 = \frac{w_2}{M_2}\right)$$

3. Mole fraction is the ratio of number of moles of solute or solvent and total number of moles of solution. It is denoted by x.

$$x_{\text{solute}} = \frac{n_2}{n_1 + n_2}, \; x_{\text{solvent}} = \frac{n_1}{n_1 + n_2}$$

4. Mass of solute = 9.8 g

Mass of solution = 100 g

Density of solution = 1.02 g mL^{-1}

$$\therefore \quad \text{Volume of solution} = \frac{\text{Mass of solution}}{\text{Density of solution}}$$

$$= \frac{100 \text{ g}}{1.02 \text{ g mL}^{-1}} = 98.039 \text{ mL} = 0.098 \text{ L}$$

$$\text{Number of moles of solute, } n = \frac{9.8}{98} = 0.1 \text{ mol}$$

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

$$= \frac{0.1 \text{ mol}}{0.098 \text{ L}} = 1.02 \text{ M}$$

5.

Molarity	Molality
Number of moles of solute dissolved in one litre solution is called molarity.	Number of moles of solute dissolved in one kg solvent is called molality.
$M = \dfrac{\text{No. of moles of solute}}{\text{Volume of solution in litre}}$	$m = \dfrac{\text{No. of moles of solute}}{\text{Mass of solvent in kg}}$
Molarity depends on temperature as volume depends on temperature. Molarity decreases with rise in temperature.	Molality is independent of temperature as mass does not change with temperature.

If M_B is the molar mass of solute, d is the density of solution then molality (m) of a solution can be converted to molarity (M) by using the formula,

$$M = \frac{md}{\left(1 + \dfrac{mM_B}{1000}\right)}$$

6. Mass of solution = 100 g

Mass of solute = 10 g

Mass of solvent = 100 – 10 = 90 g = 0.09 kg

$$\text{Number of moles of solute, } n = \frac{10}{180} = 0.055 \text{ mol}$$

$$m = \frac{0.055 \text{ mol}}{0.09 \text{ kg}} = 0.61 \text{ m}$$

7. *Refer to answer 5.*

8. *Refer to answer 5.*

If M_B is the molar mass of solute, d is the density of solution then molarity (M) value of a solution can be converted into its molality (m) by using the following formula,

$$m = \frac{1000 \times M}{(1000 \times d) - (M \times M_B)}$$

9. Given : Mass of solute, $W_2 = 10$ g

Mass of solvent, $W_1 = 90$ g

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

Density of solution = 1.2 g mL^{-1}

(i) $\text{Molality} = \dfrac{W_2 \times 1000}{M_2 \times W_1} = \dfrac{10 \times 1000}{180 \times 90}$

= 0.62 m

(ii) $\text{Volume of solution} = \dfrac{\text{mass}}{\text{density}} = \dfrac{100 \text{ g}}{1.2 \text{ g mL}^{-1}}$

$$\text{Molarity} = \frac{W_2 \times 1000}{M_2 \times V}$$

$$M = \frac{10 \times 1000}{180 \times \dfrac{100}{1.2}} = \frac{10 \times 1000 \times 1.2}{180 \times 100} = 0.67 \text{ M}$$

10. Increase in temperature decreases the solubility of oxygen in water. As a result, amount of dissolved oxygen decreases. It becomes more difficult to breathe as oxygen is less. Hence, the aquatic species are not comfortable in warm water.

11. According to Henry's law, the solubility of a gas is inversely proportional to the Henry's law constant (K_H) for that gas. Hence, gas (B) being less soluble, would have a higher K_H value.

12. Henry's law states that, the partial pressure of the gas in vapour phase (p) is proportional to the mole fraction of the gas (x) in the solution.
$p = K_H \cdot x$ where, K_H = Henry's law constant. Different gases have different K_H values at the same temperature.

13. *Refer to answer 12.*

14. To minimise the painful effects of decompression sickness in deep sea divers, oxygen diluted with less soluble helium gas is used as breathing gas

15. *Refer to answer 12.*

$$\text{Solubility of CO}_2 = \frac{p}{K_H} = \frac{760}{1.25\times10^6} = 6.08\times10^{-4}$$

16. (a) *Refer to answer 10.*

(b) At high altitudes, the partial pressure of oxygen is less than at the ground level. As a result, there is a low concentration of oxygen in the blood and tissues of the people living at high altitudes. Thus, they feel weak and are unable to think properly.

17. *Refer to answer 12.*

Applications of Henry's law :

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

(ii) To minimise the painful effects of decompression sickness in deep sea divers, oxygen diluted with less soluble helium gas is used as breathing gas.

18. *Refer to answer 10.*

19. Applying the relationship,

$m = K_H \times p$

In the first case, $6.56 \times 10^{-2}\text{ g} = K_H \times 1\text{ bar}$

or, $K_H = 6.56 \times 10^{-2}\text{ g bar}^{-1}$

In the second case,

$5.0 \times 10^{-2}\text{ g} = (6.56 \times 10^{-2}\text{ g bar}^{-1}) \times p$

$$p = \frac{5.0\times10^{-2}\text{ g}}{6.56\times10^{-2}\text{ g bar}^{-1}} = 0.762\text{ bar}$$

20. According to Henry's law, $p_{N_2} = K_H \times x_{N_2}$

$$x_{N_2} = \frac{p_{N_2}}{K_H} = \frac{0.987\text{ bar}}{76480\text{ bar}} = 1.29\times10^{-5}$$

If n moles of N_2 are present in 1 L (*i.e.*, 55.55 moles), of water

$$x_{N_2} = \frac{n}{n+55.55} \simeq \frac{n}{55.55}$$

$$\therefore \quad \frac{n}{55.55} = 1.29\times10^{-5}$$

or $\quad n = 1.29 \times 10^{-5} \times 55.55$ moles

$= 71.659 \times 10^{-5}$ moles $= 0.716$ millimoles

21. Liquid A

22. **Raoult's law :** For a solution of volatile liquids, the partial pressure of each component in the solution is directly proportional to its mole fraction. Thus, for any component, partial vapour pressure, $p \propto x \Rightarrow p = p^\circ . x$

where, p° = vapour pressure of pure component

x = mole fraction of that component

23. *Refer to answer 22.*

24. *Refer to answer 22.*

Henry's law : If gas is the solute and liquid is the solvent, then according to Henry's law,

$p = K_H \cdot x$

i.e., partial pressure of the volatile component (gas) is directly proportional to the mole fraction of that component (gas) in the solution.

Hence, Raoult's law and Henry's law has been identical except that their proportionality constant are different. It is equal to p° for Raoult's law and K_H for Henry's law.

Therefore, Raoult's law becomes a special case of Henry's law in which K_H becomes equal to vapour pressure of pure component p°.

25. *Refer to answer 22.*

Let a solution consists of two volatile liquids A and B with their mole fractions x_A and x_B respectively. If p_A and p_B are their partial vapour pressures, then,

$p_A \propto x_A \Rightarrow p_A = p_A^\circ x_A$ and $p_B \propto x_B \Rightarrow p_B = p_B^\circ x_B$

where p_A° and p_B° represent the vapour pressures of pure liquid components A and B.

$P_{total} = p_A + p_B$

Ideal solutions obey Raoult law at all concentrations and temperature.

26. *Refer to answer 22.*

Raoult's law for solution containing non-volatile solute : It states that partial vapour pressure of a solution of non-volatile solute, p_{solution} is directly proportional to the mole fraction of the solvent in the solution.

Mathematically,

$p_{\text{solution}} = p^{\circ}_{\text{solvent}} \times x_{\text{solvent}}$

where, $p^{\circ}_{\text{solvent}}$ = vapour pressure of the pure solvent at the given temperature.

or, $\dfrac{p^{\circ} - p_{\text{solution}}}{p^{\circ}} = x_2$

27. Given : $p^{\circ}_A = 450$ mm Hg, $p^{\circ}_B = 700$ mm Hg, $P_{\text{Total}} = 600$ mm Hg, $x_A = ?$

Applying Raoult's law, $p_A = x_A \times p^{\circ}_A$

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

$P_{\text{Total}} = p_A + p_B = x_A \times p^{\circ}_A + (1 - x_A)p^{\circ}_B$

$= p^{\circ}_B + (p^{\circ}_A - p^{\circ}_B)x_A$

Substituting the given values, we get

$600 = 700 + (450 - 700)x_A$ or, $250x_A = 100$

or $x_A = \dfrac{100}{250} = 0.40$

Thus, composition of the liquid mixture will be

$x_A = 0.40; x_B = 1 - 0.40 = 0.60$

Calculation of composition in the vapour phase,

$p_A = x_A \times p^{\circ}_A = 0.40 \times 450$ mm Hg = 180 mm Hg

$p_B = x_B \times p^{\circ}_B = 0.60 \times 700$ mm Hg = 420 mm Hg

Mole fraction of A in the vapour phase

$$= \frac{p_A}{p_A + p_B} = \frac{180}{180 + 420} = 0.30$$

Mole fraction of B in the vapour phase $= 1 - 0.30$

$= 0.70$

28. A mixture of ethanol and acetone shows positive deviation from Raoult's law. Pure ethanol possesses hydrogen bonding. Introduction of acetone between the molecules of ethanol results in breaking of some of these hydrogen bonds. Due to weakening of interactions, the solution shows positive deviation from Raoult's law.

29. A solution which obeys Raoult's law of vapour pressure for all compositions is called ideal solution.

In this solution $\Delta V_{\text{mix}} = 0$, $\Delta H_{\text{mix}} = 0$

$A \ldots. B$ interaction = $A \ldots. A$ and $B \ldots. B$ interactions.

30. Non-ideal solutions that show negative deviation from Raoult's law form maximum boiling azeotropes.

31. Azeotropes are the binary mixtures of solutions that have the same composition in liquid and vapour phases and that have constant boiling point.

32. *Refer to answer 31.*

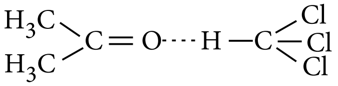
33. The differences between ideal solutions and non ideal solutions are as follows :

(i) In ideal solutions $\Delta V_{\text{mixing}} = 0$ and $\Delta H_{\text{mix}} = 0$ whereas in non ideal solutions,

$$\Delta V_{\text{mix}} \neq 0 \text{ and } \Delta H_{\text{mix}} \neq 0.$$

(ii) In ideal solutions, each component obeys Raoult's law at all temperatures and concentrations whereas in non ideal solutions, they do not obey Raoult's law.

34. Mixture of chloroform and acetone shows negative deviation from Raoult's law, thus it forms maximum boiling azeotrope. This is because chloroform molecule is able to form hydrogen bond with acetone molecule as shown :

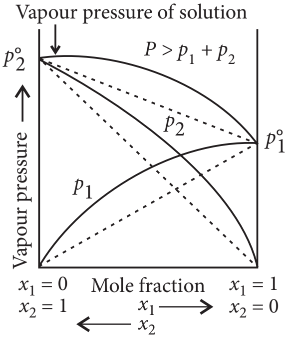


This decreases the escaping tendency of molecules for each component and consequently the vapour pressure decreases resulting in negative deviation from Raoult's law.

35. **Positive deviation :** For non-ideal solutions, if the vapour pressure is higher, then it is said to exhibit positive deviation.

A—B interactions are weaker than A—A or B—B interactions. Due to this, vapour pressure increases which results in positive deviation.

In positive deviation, intermolecular force decreases, volume increases, vapour pressures increases. enthalpy increases. Therefore, ΔH_{mix} = +ve, ΔV_{mix} = + ve. *e.g.*, ethanol + acetone and carbon disulphide + acetone show positive deviation.

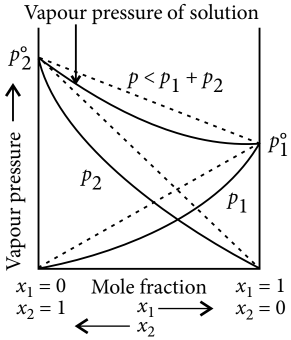


Plot for non-ideal solution showing positive deviation

36. *Refer to answer 31.*

A minimum boiling azeotrope is formed by solutions showing a large positive deviation from Raoult's law at a specific composition. For example an ethanol-water mixture containing approximately 95% ethanol by volume.

37. Negative deviation : For non-ideal solution, if the vapour pressure is lower, then it is said to exhibit negative deviation. $A—B$ interactions are stronger than $A—A$ and $B—B$ interactions. Due to this, vapour pressure decreases which results in negative deviation. In negative deviation, intermolecular force increases, volume decreases, vapour pressure decreases and heat is released. Therefore, $\Delta H_{mix} = -\text{ve}$, $\Delta V_{mix} = -\text{ ve}$. For example, phenol + aniline and chloroform + acetone show negative deviation.



Plot for non-ideal solution showing negative deviation

38. *Refer to answer 31.*

A maximum boiling azeotrope is formed by solutions showing a large negative deviation from Raoult's law at a specific composition.

For example, chloroform + acetone mixture.

39. *Refer to answer 28*

40. *Refer to answers 35 and 37.*

41. *Refer to answers 34.*

42. (a) : Colligative properties of ideal solutions depend only on the number of particles of solute dissolved in a definite amount of the solvent and do not depend on the nature of solute.

43. When the external pressure applied becomes more than the osmotic pressure of solution then the solvent molecules from the solution pass through the semi-permeable membrane to the solvent side and the process is called reverse osmosis.

44. In osmotic pressure method, pressure can be measured at room temperature and the molarity of the solution is used instead of molality. That is why this method is used for determination of molar masses of macromolecules as they are generally not stable at higher temperatures.

45. Properties which depend upon the number of solute particles irrespective of their nature relative to the total number of particles present in the solution are called colligative properties.

46. Osmotic pressure is the extra pressure which is applied on the solution to just prevent the flow of solvent into the solution through a semi-permeable membrane.

47. Two solutions having same osmotic pressure at a given temperature are called isotonic solutions.

48. Molal elevation constant may be defined as the elevation in boiling point when the molality of the solution is unity (*i.e.*, 1 mole of the solute is dissolved in 1 kg (1000 g) of the solvent). The units of K_b are therefore, degree/molality *i.e.*, K/m or °C/m or K kg mol^{-1}.

49. When a non-volatile solute is added to a solvent, the vapour pressure of the solvent (above the resulting solution) is lower than the vapour pressure above the pure solvent.

50. *Refer to answer 48.*

51. Molality (m) of urea solution

$$= \frac{w \times 1000}{M \times \text{Mass of solvent}} = \frac{5 \times 1000}{60 \times 95} = 0.877 \text{ m}$$

Osmotic pressure (π) = CRT

$$= 0.877 \times 0.0821 \times 300 = 21.6 \text{ atm}$$

52. Molality (m) of urea $= \dfrac{7.5 \times 1000}{60 \times 100} = 1.25$ m ...(i)

$$\text{Molality of substance, } Z = \frac{42.75 \times 1000}{\text{Molar mass} \times 100}$$

$$= \frac{427.5}{\text{Mol. mass}} \quad \text{...(ii)}$$

As both the solutions have same depression in freezing point so they have same molality.

From eqn. (i) and (ii), we get

$$1.25 = \frac{427.5}{\text{Molar mass}}$$

Molar mass of Z = 342 g/mol

53. (i) As KCl is an electrolyte and one formula unit of KCl dissociates to give two ions (K^+ and Cl^-), therefore molar concentration of particles in the solution = 0.1 × 2 M = 0.2 M

As elevation of boiling point (or any colligative property) is directly proportional to number of particles in solution, hence 0.1 M KCl has higher boiling point that 0.1 M glucose.

(ii) Salting is used because most bacteria, fungi and other potentially pathogenic organism cannot survive in a highly salty environment, due to the hypertonic nature of salt. Any living cell in such an environment will become dehydrated through osmosis and die or become temporarily deactivated.

54. Mass of glucose ($C_6H_{12}O_6$), $W_2 = 60$ g

Mass of water, $W_1 = 250$ g

M_2 (Mol. mass of $C_6H_{12}O_6$) = 180 g mol^{-1}

$K_f = 1.86$ K kg mol^{-1}, $T_f = ?$

Using formula, $K_f \times \dfrac{W_2 \times 1000}{M_2 \times W_1}$

$$= 1.86 \times \frac{31 \times 1000}{62 \times 500}\ \text{K}$$

$\Delta T_f = T_f^\circ - T_f$

or $T_f = T_f^\circ - \Delta T_f = 273 - 1.86 = 271.14$ K

55. (i) The elevation in boiling point of a solution is a colligative property which depends on the number of moles of solute added. Higher the concentration of solute added, higher will be the elevation in boiling point. Thus, 2 M glucose has higher boiling point than 1 M glucose solution.

(ii) *Refer to answer 43.*

56. (i) 1.2% sodium chloride solution is hypertonic with respect to 0.9% sodium chloride solution or blood cells thus, on placing blood cells in this solution exosmosis takes place that results in shrinking of cells.

(ii) 0.4% sodium chloride solution is hypotonic with respect to 0.9% sodium chloride solution or blood cells thus, on placing blood cells in this solution endosmosis takes place that results in swelling of cells.

57. The boiling point of the solution is always higher than that of the pure solvent. As the vapour pressure of the solution is lower than that of the pure solvent and vapour pressure increases with increase in temperature, hence, the solution has to be heated more to make the vapour pressure equal to the atmospheric pressure.

Elevation of boiling point is a colligative property because it depends on number of solute particles present in a solution.

58. Given : $W_2 = ?$, $M_2 = 256$ g mol^{-1}, $\Delta T_f = 0.48$ K

$W_1 = 75$ g, $K_f = 5.12$ K kg mol^{-1}

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

$$W_2 = \frac{\Delta T_f \times M_2 \times W_1}{K_f \times 1000} = \frac{0.48 \times 256 \times 75}{5.12 \times 1000} = 1.8\ \text{g}$$

59. Given, $W_1 = 1$ kg = 1000 g, $W_2 = 18$ g,

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

$T_b^\circ = 373.15$ K, $K_b = 0.52$ K Kg mol^{-1}, $T_b = ?$

Using formula,

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

or $$\Delta T_b = \frac{0.52 \times 18 \times 1000}{180 \times 1000} = 0.052\ \text{K}$$

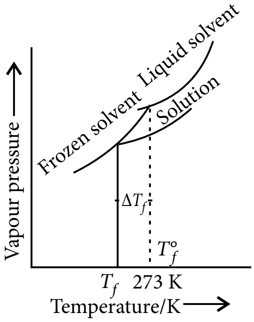
$\Delta T_b = T_b - T_b^\circ$

$0.052 = T_b - 373.15$

$T_b = 373.15 + 0.052 = 373.202$ K

60. When a non-volatile solute is added to a solvent, the freezing point of the solution is always lower than that of pure solvent as the vapour pressure of the solvent decreases in the presence of non-volatile solute.

Plot for the lowering in freezing point of water when NaCl is added to it is shown as :



61. Osmosis : The spontaneous movement of the solvent molecules from the pure solvent or from a dilute solution to a concentrated solution through a semi-permeable membrane is called osmosis.

Osmotic Pressure : The minimum excess pressure that has to be applied on the solution to prevent the passage of solvent molecules into it through semipermeable membrane is called osmotic pressure.

Osmotic pressure is a colligative property because it depends on the number of solute particles and not on their nature.

62. (i) Number of particles of solute
(ii) Association or dissociation of solute
(iii) Concentration of solute
(iv) Temperature

63. Given, $M_2 = 176$ g mol^{-1}, $\Delta T_f = 1.5°C$
$w_1 = 75$ g, $K_f = 3.9$ K kg mol^{-1}, $w_2 = ?$

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

$$w_2 = \frac{\Delta T_f \times M_2 \times w_1}{K_f \times 1000} = \frac{1.5 \times 176 \times 75}{3.9 \times 1000} = 5.077 \text{ g}$$

64. Molality of sucrose solution (m)

$$= \frac{w_2 \times 1000}{M_2 \times w_1} = \frac{4 \times 1000}{342 \times 96} = 0.121 \text{ m}$$

ΔT_f for sucrose solution = 273.15 – 271.15 = 2 K

$$K_f = \frac{\Delta T_f}{m} = \frac{2}{0.121} = 16.52 \text{ K/m}$$

$$\text{Molality of glucose solution} = \frac{5 \times 1000}{180 \times 95} = 0.292 \text{ m}$$

$\Delta T_f = K_f \times m = 16.52 \times 0.292 = 4.82$ K
Freezing point of glucose solution
= 273.15 – 4.82 = 268.33 K

65. $\pi = cRT,\ c = \dfrac{w_2}{M_2 \times V}$

w_2 = weight of solute
M_2 = molar mass of solute

$$\frac{\pi_1}{\pi_2} = \frac{c_1 RT_1}{c_2 RT_2}. \text{ Given, } T_1 = T_2$$

$$\frac{\pi_1}{\pi_2} = \frac{c_1}{c_2} \Rightarrow \frac{4.98}{1.52} = \frac{\dfrac{30}{180 \times 1}}{c_2}$$

$$\Rightarrow c_2 = \frac{30 \times 1.52}{180 \times 4.98} = 0.051 \text{ mol/L}$$

66. Molality (m) of sucrose solution

$$= \frac{w \times 1000}{M \times \text{Mass of solvent}} = \frac{10}{342} \times \frac{1000}{90} = 0.325 \text{ m}$$

ΔT_f for sucrose solution
$= T_f^\circ - T_f = (273.15 - 269.15)$ K = 4 K

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

$$\therefore \quad K_f = \frac{\Delta T_f}{m} = \frac{4 \text{ K}}{0.325 \text{ m}} = 12.308 \text{ K/m}$$

$$\text{Molality of glucose solution} = \frac{10}{180} \times \frac{1000}{90} = 0.617 \text{ m}$$

$\Delta T_f = K_f \times m$

$\therefore \quad \Delta T_f = 12.308 \text{ K/m} \times 0.617 \text{ m} = 7.59 = 7.6$ K

$\therefore \quad$ Freezing point of glucose solution,

$T_f^\circ - \Delta T_f = (273.15 - 7.60)$ K = 265.55 K

67. Given, weight of urea (W_2) = 30 g
Weight of water (W_1) = 846 g
Vapour pressure of water $p_1^\circ = 23.8$ mm Hg

$$n_B = \frac{30}{60} = 0.5,\quad n_A = \frac{846}{18} = 47$$

$$\text{Mole fraction of water } (x_A) = \frac{n_A}{n_A + n_B}$$

$$= \frac{47}{47 + 0.5} = \frac{47}{47.5} = 0.99$$

$P_A = p_A^\circ \times x_A = 23.8 \times 0.99 = 23.5$ mm Hg.

68. Mass of $CaCl_2$ (W_2) = 10 g
Mass of water (W_1) = 200 g
Molar mass of $CaCl_2$ (M_2) = 111 g mol^{-1}
Molal elevation constant (K_b) = 0.512 K kg mol^{-1}

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

$$m = \frac{10}{111} \times \frac{1000}{200} = 0.450 \text{ m}$$

$\Delta T_b = iK_b\, m = 3 \times 0.512 \times 0.450 = 0.6912$ K

69. Mass of ethylene glycol ($C_2H_6O_2$), $W_2 = 31$ g
Mass of water, $W_1 = 500$ g
M_2 (Mol. mass of $C_2H_6O_2$) = 62 g mol^{-1},
$K_f = 1.86$ K kg mol^{-1}, $T_f = ?$

$$\text{Using formula, } \Delta T_f = K_f \times \frac{W_2 \times 1000}{M_2 \times W_1}$$

$$= 1.86 \times \frac{31 \times 1000}{62 \times 500} \text{ K}$$

$$\Delta T_f = T_f^\circ - T_f$$

$$\text{or } T_f = T_f^\circ - \Delta T_f = 273 - 1.86 = 271.14 \text{ K}$$

70. Mass of urea = 15 g
Molar mass of urea = 60 g mol^{-1}
Molar mass of glucose = 180 g mol^{-1}
Mass of glucose = ?

For isotonic solution, osmotic pressure, $\pi_1 = \pi_2$

$n_1 = n_2$ (when volume is same)

$$\text{or} \quad \frac{W_1}{M_1} = \frac{W_2}{M_2} \Rightarrow \frac{15}{60} = \frac{W_2}{180}$$

$$\Rightarrow \quad W_2 = \frac{15\times 180}{60} = 45 \text{ g}$$

71. (i) *Refer to answer 46.*

(ii) *Refer to answer 45.*

72. $T_f = -15°\text{C}, K_f = 1.86 \text{ K kg mol}^{-1}$

$\Delta T_f = T_f^\circ - T_f = 0 - (-15°\text{C}) = 15°\text{C}$

$\Delta T_f = K_f \times m$

$15 = 1.86 \times$ moles of solute $= 40.32$ moles

$\Delta T_b = K_b \times m$

$$\Delta T_b = 0.52 \times \frac{\text{moles of solute}}{\text{mass of solvent (kg)}}$$

$$\Delta T_b = 0.52 \times \frac{40.32}{5 \text{ kg}} = 4.19$$

$\Delta T_b = T_b - T_b^\circ$

$4.19 = T_b - 373$

$T_b = 373 + 4.19 = 377.19 \text{ K}$

73. $W_2 = 1.00 \text{ g}, W_1 = 50 \text{ g}, K_f = 5.12 \text{ K kg mol}^{-1}$, $\Delta T_f = 0.40 \text{ K}$

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

$$M_2 = \frac{K_f \times W_2 \times 1000}{W_1 \times \Delta T_f} = \frac{5.12 \times 1 \times 1000}{50 \times 0.40}$$

$$= 256 \text{ g mol}^{-1}$$

74. Molality of sugar solution

$$= \frac{W_2 \times 1000}{M_2 \times W_1} = \frac{5}{342} \times \frac{1000}{95} = 0.154 \text{ m}$$

$\Delta T_f = T_f^\circ - T_f = 273.15 - 271 = 2.15 \text{ K}$

$$\Delta T_f = K_f \times m \quad \therefore \; K_f = \frac{\Delta T_f}{m} = \frac{2.15}{0.154}$$

Molality of glucose solution

$$= \frac{W_2 \times 1000}{M_2 \times W_1} = \frac{5}{180} \times \frac{1000}{95} = 0.292 \text{ m}$$

$$\therefore \quad \Delta T_f(\text{Glucose}) = K_f \times m = \frac{2.15}{0.154} \times 0.292 = 4.08$$

$\therefore$ Freezing point of glucose solution

$= 273.15 - 4.08 = 269.07 \text{ K}$

75. $W_1 = 500 \text{ g}$

Boiling point of solution $(T_b) = 100.42°\text{C}$

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

$M_2(C_3H_8O_3)$

$= (3 \times 12) + (8 \times 1) + (3 \times 16)$

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

$\Delta T_b = T_b - T_b^\circ$

$= 373.42 \text{ K} - 373 \text{ K} = 0.42 \text{ K}$

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

$$W_2 = \frac{\Delta T_b \times M_2 \times W_1}{K_b \times 1000} = \frac{0.42 \times 92 \times 500}{0.512 \times 1000} = 37.73 \text{ g}$$

76. The relative lowering of vapour pressure is given by the following expression,

$(p^\circ_{\text{solvent}} - p_{\text{solution}})/p^\circ_{\text{solvent}} = n_2/(n_1 + n_2)$

for dilute solutions, $n_2 << n_1$, therefore

$(p^\circ_{\text{solvent}} - p_{\text{solution}})/p^\circ_{\text{solvent}} = n_2/n_1$

$= (W_2 \times M_1)/(M_2 \times W_1)$

$(p^\circ_{\text{solvent}} - 2.8)/p^\circ_{\text{solvent}} = (30 \times 18)/(M_2 \times 90)$

$(p^\circ_{\text{solvent}} - 2.8)/p^\circ_{\text{solvent}} = 6/M_2$ ...(1)

Similarly for second case we get,

$(p^\circ_{\text{solvent}} - 2.9)/p^\circ_{\text{solvent}} = (30 \times 18)/(M_2 \times 108)$

$(p^\circ_{\text{solvent}} - 2.9)/p^\circ_{\text{solvent}} = 5/M_2$ ...(2)

Divides eq. (1) by (2), we get

$(p^\circ_{\text{solvent}} - 2.8)/(p^\circ_{\text{solvent}} - 2.9) = 6/5$

$\therefore \quad p^\circ_{\text{solvent}} = 3.4 \text{ kPa}$

i.e., vapour pressure of water at 298 K is 3.4 kPa

Substituting the value of p°_{solvent} in (1) we get,

$(3.4 - 2.8)/3.4 = 6/M_2$ or $0.6/3.4 = 6/M_2$

$\therefore \quad M_2 = 34 \text{ g}$

77. $i = 2, K_b = 0.512 \text{ K kg mol}^{-1}, W_B = 15 \text{ g}$

$M_B = 58.44 \text{ g mol}^{-1}, W_A = 250 \text{ g}$

$$\Delta T_b = \frac{i \times K_b \times W_B \times 1000}{M_B \times W_A}$$

$$\Delta T_b = \frac{2 \times 0.512 \times 15 \times 1000}{58.44 \times 250} = 1.05 \text{ K}$$

Therefore, boiling point of aqueous solution,

$T_b = T_b^\circ + \Delta T_b = 373.15 \text{ K} + 1.05 \text{ K} = 374.20 \text{ K}$

78. $W_B = 8.95 \text{ mg} = 8.95 \times 10^{-3} \text{ g}$,

$R = 0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1}, V = 35 \times 10^{-3} \text{ L}$

$$T = (25 + 273) \text{ K} = 298 \text{ K}, \; \pi = \frac{0.335}{760} \text{atm}$$

Substituting these values in the equation,

$$M_B = \frac{W_B \times R \times T}{\pi \times V}$$

$$M_B = \frac{8.95 \times 10^{-3} \text{ g} \times 0.0821 \text{ L atm K}^{-1} \text{ mol}^{-1} \times 298 \text{ K}}{\frac{0.335}{760} \text{atm} \times 35 \times 10^{-3} \text{ L}}$$

$M_B = 14193.29 \text{ g mol}^{-1}$

79. $W_2 = 6.21$ g, $W_1 = 24.0$ g
$T_b = 68.04$ °C, $T_b^\circ = 61.7$ °C and $K_b = 3.63$ °C/m
$\Delta T_b = T_b - T_b^\circ = 68.04 \text{ °C} - 61.7 \text{ °C} = 6.34 \text{ °C}$

$$\Delta T_b = \frac{K_b \times W_2 \times 1000}{M_2 \times W_1} \text{ or } M_2 = \frac{K_b \times W_2 \times 1000}{\Delta T_b \times W_1}$$

$$M_2 = \frac{3.63\text{°C m}^{-1} \times 6.21 \text{ g} \times 1000}{6.34\text{°C} \times 24.0 \text{ g}} = 148.15 \text{ g mol}^{-1}$$

80. (i) Osmotic pressure can be measured at room temperature and molarity of the solution is used instead of molality.
(ii) Its magnitude is large as compared to other colligative properties even for very dilute solutions.

81. Concentration of the solution = 1 molar
Density of the solution = 1.06 g mL^{-1}
M_2, molar mass of KBr = 39 + 80 = 119 g mol^{-1}
K_b for H_2O = 0.52 K kg mol^{-1}

$$\text{Molality, } m = \frac{M \times 1000}{1000 \times d - M \times M_2}$$

$$m = \frac{1 \times 1000}{1000 \times 1.06 - 1 \times 119} = 1.0626 \text{ mol kg}^{-1}$$

$\Delta T_b = K_b m = 0.52 \text{ K kg mol}^{-1} \times 1.0626 \text{ mol kg}^{-1}$
$\Delta T_b = 0.5525 \text{ K} \approx 0.553 \text{ K}$
$T_b = T_b^\circ + \Delta T_b = 373 \text{ K} + 0.553 \text{ K} = 373.553 \text{ K}$

82. i for 1 M KCl = 2
i for sugar solution = 1
$\therefore \Delta T_b = iK_b m = 2 K_b$ (for KCl)
$\Delta T_b = K_b$ (for sugar)
$\therefore$ ΔT_b of 1 M KCl solution is double than that of 1 M sugar solution.

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

$$i = \frac{\text{Experimental (or observed) value of colligative property}}{\text{Calculated (or normal) value of colligative property}}$$

(i) van't Hoff factor (i) > 1 for solutes undergoing dissociation
(ii) van't Hoff factor (i) < 1 for solutes undergoing association

84. The molar mass which is either lower or higher than the expected or normal value is known as abnormal molar mass.

85. *Refer to answer 83.*

86. Molecular mass of Glauber's salt ($Na_2SO_4 \cdot 10H_2O$)
$= [2 \times 23 + 32 + 16 \times 4 + 10 \times (2 \times 1 + 16)]$
$= (46 + 32 + 64 + 180) \text{ g mol}^{-1} = 322 \text{ g mol}^{-1}$
$Na_2SO_4 \cdot 10H_2O$ ionises as :
$Na_2SO_4 \cdot 10H_2O \rightleftharpoons 2Na^+ + SO_4^{2-} + 10H_2O$
$\Rightarrow$ $i = 3$

$$m = \frac{n_B}{W_A} = \frac{W_B}{M_B \times W_A} = \frac{6.00 \text{ g}}{322 \text{ g mol}^{-1} \times 0.1 \text{ kg}}$$
$$= 0.186 \text{ mol kg}^{-1} = 0.186 \text{ m}$$

Also, $\Delta T_f = i\, K_f \cdot m$
$= 3 \times 1.86 \text{ K m}^{-1} \times 0.186 \text{ m} = 1.04 \text{ K}$
$\Rightarrow$ $T_f = T_f^\circ - \Delta T_f = (273 - 1.04) \text{ K} = 271.96 \text{ K}$

87. Molality of solution, m = 1.00 m
Boiling point of solution, T_b = 100.18°C = 373.18 K
Boiling point of water (solvent), T_b° = 100.00°C = 373 K
$\Delta T_b = T_b - T_b^\circ = 373{\cdot}18 \text{ K} - 373 \text{ K} = 0{\cdot}18 \text{ K}$
$\Delta T_b = i\, K_b \cdot m$
$0.18 \text{ K} = i \times K_b \cdot m$
$0.18 \text{ K} = i \times 0.512 \text{ K kg mol}^{-1} \times 1 \text{ mol kg}^{-1}$

$$i = \frac{0.18 \text{ K}}{0.512 \text{ K kg mol}^{-1} \times 1 \text{ mol kg}^{-1}} = 0.35$$

88. *Refer to answer 83 and 85.*

89. $\pi = iCRT = i \cdot \dfrac{n}{V} RT = i \times \dfrac{w}{M} \times \dfrac{1}{V} RT$

or $4.75 = i \times \dfrac{5.85}{58.5} \times \dfrac{1}{1} \times 0.082 \times 300$

or $i = 1.93$

$$\begin{array}{llll} & NaCl \longrightarrow & Na^+ + & Cl^- \\ \text{Initial moles} & C & 0 & 0 \\ \text{Moles at eqm.} & C - \alpha & C\alpha & C\alpha \end{array}$$

Total no. of moles = $C(1 + \alpha)$

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

or, $i = 1 + \alpha$
or, $1 + \alpha = 1.93$
or, $\alpha = 0.93$ or 93%

90. (a) : Given : $W_2 = 19.5$ g,
$W_1 = 500$ g, $K_f = 1.86 \text{ K kg mol}^{-1}$
$\Delta T_{f(\text{obs})} = 1.0$

$$\therefore M_{2(\text{obs})} = \frac{1000\times K_f\times W_2}{W_1\times\Delta T_{f(\text{obs})}} = \frac{1000\times1.86\times19.5}{500\times1}$$

$$= 72.54$$

$M_{2(\text{cal})}$ for $\text{F—CH}_2\text{—COOH}$ = 78 g mol^{-1}

$$i = \frac{M_{2(\text{cal})}}{M_{2(\text{obs})}} = \frac{78}{72.54} = 1.0753$$

$$\text{F—CH}_2\text{—COOH} \rightleftharpoons \text{F—CH}_2\text{—COO}^- + \text{H}^+$$

Initial moles	C	0	0
Moles at eqm.	C – α	Cα	Cα

Total no. of moles = $C(1 + \alpha)$

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

or $\alpha = i - 1 = 1.0753 - 1 = 0.0753 = 7.53\%$

91. Given, $W_2 = 5$ g, $W_1 = 35$ g

$\Delta T_f = 2.94$ K, $K_f = 4.9$ K kg mol^{-1}

$$\Delta T_f = i\,K_f m = i\times K_f\times\frac{W_2\times1000}{M_2\times W_1}$$

or $$2.94 = i\times4.9\times\frac{5\times1000}{122\times35}$$

or $i = 0.512$

As $i < 1$, solute is associated.

$$2\text{C}_6\text{H}_5\text{COOH} \rightleftharpoons (\text{C}_6\text{H}_5\text{COOH})_2$$

Initial moles	1	0
Moles at eqm.	1 – α	α/2

Total no. of moles after association : 1 – α + α/2 = 1 – α/2

$$\therefore \quad i = \frac{1-\alpha/2}{1} = 1-\frac{\alpha}{2} \text{ or } 1-\frac{\alpha}{2} = 0.512$$

or $\alpha = 2\times(1 - 0.512) = 0.976$ or 97.6%

92. $\Delta T_f = iK_f\cdot m$

i for $\text{MgCl}_2 = 3$

$$\text{Molality, } m = \frac{W_2\times1000}{M_2\times W_1} = \frac{1.9\times1000}{95\times50} = 0.4 \text{ m}$$

$\Delta T_f = 3\times1.86\times0.4 = 2.232$ K

Freezing point of solution, $T_f = T_f^\circ - \Delta T_f$

$= 273 - 2.232 \text{ K} = 270.77$ K

93. $W_2 = 2.56$ g, $W_1 = 100$ g, $\Delta T_f = 0.383$ K

$K_f = 3.83$ K kg mol^{-1}, $\Delta T_f = K_f\times m$

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

$$\Rightarrow \quad M_2 = \frac{W_2\times1000}{\Delta T_f\times W_1}\times K_f$$

$$= \frac{2.56\times1000}{0.383\times100}\times3.83 = 256 \text{ g mol}^{-1}$$

$$\because \quad i = \frac{\text{Normal atomic mass}}{\text{Observed atomic mass}} = \frac{32}{256} = \frac{1}{8}$$

Sulphur exists as S_8.

94. $W_2 = 4$ g, $M_2 = 120$ g mol^{-1}

$W_1 = 100$ g, $K_b = 0.52$ K kg mol^{-1}

For complete dissociation, $i = 2$

Using formula, $\Delta T_b = iK_b m$

or $$\Delta T_b = \frac{i\times K_b\times W_2\times1000}{M_2\times W_1}$$

$$= 2\times0.52\times\frac{4\times1000}{120\times100} = 0.34 \text{ K}$$

$\therefore \quad T_b = T_b^\circ + \Delta T_b = 100 + 0.34 = 100.34$°C

95. $W_2 = 3.9$ g, $W_1 = 49$ g,

$\Delta T_f = 1.62$ K, $M_2 = 122$ g mol^{-1},

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

$$\Delta T_f = i\,K_f m = i\times K_f\times\frac{W_2\times1000}{M_2\times W_1}$$

$$\Rightarrow \quad 1.62 = \frac{i\times4.9\times3.9\times1000}{122\times49}$$

$$\Rightarrow \quad i = \frac{1.62\times122\times49}{4.9\times3.9\times1000} = 0.506$$

As $i < 1$, solute is associated.

96. $$\Delta T_f = iK_f m = \frac{i\times K_f\times W_2\times1000}{M_2\times W_1}$$

$$2 = \frac{2\times1.86\times W_2\times1000}{58.5\times37.2}$$

$\Rightarrow \quad W_2 = 1.17$ g

97. Mass of K_2SO_4, $W_2 = 2.5\times10^{-2}$ g

Molar mass of K_2SO_4, $M_2 = 174$ g mol^{-1}

$V = 2$ L, $T = 25$°C = 298 K

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

$$\text{We know, osmotic pressure, } \pi = \frac{W_2RT}{M_2V}$$

$$\pi = \frac{2.5\times10^{-2}\times0.0821\times298}{174\times2}$$

$$= \frac{61.1645\times10^{-2}}{348} = 0.1758\times10^{-2} \text{ atm}$$

98. $\Delta T_f = 2$ K, $K_f = 1.86$ K kg mol^{-1}, $W_1 = 1$ kg, $\Delta T_f = i\,K_f m$, $M_2(\text{KCl}) = 74.5$ g mol^{-1}

$i = 2$ for KCl

$$\Delta T_f = \frac{i\times K_f\times W_2\times1000}{M_2\times W_1}$$

$$2 = \frac{2 \times 1.86 \times W_2 \times 1000}{74.5 \times 1000}$$

$\Rightarrow \quad W_2 = 40.05 \text{ g}$

99. $W_1 = 450$ g, $W_2 = 15.0$ g

$\Delta T_f = T_f^\circ - T_f = 273 \text{ K} - 272.66 \text{ K} = 0.34 \text{ K}$

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

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

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

$$M_2 = \frac{1.86 \times 15 \times 1000}{0.34 \times 450} = 182.35 \text{ g mol}^{-1}$$

100. $W_2 = 10.50$ g, $W_1 = 200$ g

$M_2(\text{MgBr}_2) = 184 \text{ g mol}^{-1}$

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

$\text{MgBr}_{2(aq)} \rightarrow \text{Mg}^{2+}_{(aq)} + 2\text{Br}^-_{(aq)}$, $i = 3$

$$\Delta T_f = iK_f m, \quad \Delta T_f = \frac{i \times K_f \times W_2 \times 1000}{M_2 \times W_1}$$

$$\Delta T_f = \frac{3 \times 1.86 \times 10.50 \times 1000}{184 \times 200} = 1.592 \text{ K}$$

Freezing point of solution, $T_f = T_f^\circ - \Delta T_f$
$= 273 - 1.592 = 271.408 \text{ K}$

101. $m = 0.561$ m, $\Delta T_f = 2.93$°C and

$K_f = 1.86°\text{C kg mol}^{-1}$

$\Delta T_f = iK_f m$

$$i = \frac{\Delta T_f}{K_f m} = \frac{2.93°\text{C}}{1.86°\text{C kg mol}^{-1} \times 0.561 \text{ m}} = 2.807$$

102. Here, $n = 2$ because phenol forms dimer on association.

$W_2 = 20$ g, $W_1 = 1$ kg $= 1000$ g, $\Delta T_f = 0.69$ K, $K_f = 5.1 \text{ K m}^{-1}$

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

$$M_2 = \frac{K_f \times W_2 \times 1000}{\Delta T_f \times W_1} = \frac{5.1 \times 20 \times 1000}{0.69 \times 1000} = 147.82$$

$M_{2(\text{observed})} = 147.82$

$M_{2(\text{calculated})}$

$\text{C}_6\text{H}_5\text{OH} = 6 \times 12 + 6 \times 1 + 16 = 94 \text{ g mol}^{-1}$

$$i = \frac{M_{2(\text{calculated})}}{M_{2(\text{observed})}} = \frac{94}{147.82} = 0.635$$

$$2\text{C}_6\text{H}_5\text{OH} \rightleftharpoons (\text{C}_6\text{H}_5\text{OH})_2$$

$$\alpha = \frac{i-1}{\left(\frac{1}{n}-1\right)} = \frac{0.635-1}{\left(\frac{1}{2}-1\right)} = \frac{0.365}{0.5} = 0.73 = 73\%$$

103. Here, $n = 3$ because 1 molecule of BaCl_2 on dissociation gives three ions.

$W_2 = 12.48$ g, $W_1 = 1.0$ kg $= 1000$ g

$T_b = 373.0832$ K, K_b for $\text{H}_2\text{O} = 0.52 \text{ K m}^{-1}$

and $M_2(\text{BaCl}_2) = 208.34 \text{ g mol}^{-1}$

$\Delta T_b = T_b - T_b^\circ = 373.0832 \text{ K} - 373 \text{ K} = 0.0832 \text{ K}$

$$M_{2(\text{observed})} = \frac{K_b \times W_2 \times 1000}{\Delta T_b \times W_1}$$

$$M_{2(\text{observed})} = \frac{0.52 \times 12.48 \times 1000}{0.0832 \times 1000} = 78$$

$M_{2(\text{observed})} = 78 \text{ g mol}^{-1}$

$$i = \frac{M_{2(\text{calculated})}}{M_{2(\text{observed})}} = \frac{208.34 \text{ g mol}^{-1}}{78 \text{ g mol}^{-1}} = 2.67$$

$$\alpha = \frac{i-1}{n-1} = \frac{2.67-1}{3-1} = \frac{1.67}{2} = 0.835 = 83.5\%$$

104. $W_1 = 65.0$ g, $\Delta T_f = 7.50$°C,

$K_f = 1.86$°C/m, $i = 1.87$ and $M_2 = 58.5 \text{ g mol}^{-1}$

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

$$W_2 = \frac{\Delta T_f \times M_2 \times W_1}{i \times K_f \times 1000} = \frac{7.50 \times 58.5 \times 65}{1.87 \times 1.86 \times 1000} = 8.199 \text{ g}$$