

# Solutions

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## 1 One Mark Questions

### 1.1 What is osmotic pressure?

The hydrostatic pressure (on the side of solution) that stops osmotic pressure of the solution.

OR

The excess of pressure on the side of the solution that stops the net flow of solvent into solution through a semipermeable membrane is called as osmotic pressure.

### 1.2 A solution concentration is expressed in molarity and not in molality while considering osmotic pressure. Why?

1. The osmotic pressure measurement are made at a specific constant temperature. Molarity remains constant at specific temperature. Molarity remains constant at specific temperature.
2. It is not necessary to express concentration in a temperature-independent unit like molality.

Hence, the solute concentration is expressed in molarity while calculating osmotic pressure rather than molality while calculating osmotic pressure rather than molality.

### 1.3 Write the equation relating boiling point elevation to to the concentration of the solution.

The boiling point elevation is directly proportional to the molality of the solution. Thus,

$$\Delta T_b \propto m \quad (1)$$

$$T_b \propto K_b m \quad (2)$$

where, m is the molality of solution. The proportionality constant  $k_b$  is called boiling point elevation constant or molal elevation constant or ebullioscopic constant.

## 1.4 What is van't Hoff factor?

van't Hoff factor ( $i$ ) is defined as the ratio of colligative property of a solution of electrolyte divided by the colligative property of non electrolyte solution of the same concentration.

Thus,

$$\frac{\text{colligative property of electrolyte solution}}{\text{colligative property of non - electrolyte solution of the same solution of the same concentration}} \quad (3)$$

$$\frac{\Delta T_f}{(\Delta T_f)_0} = \frac{\Delta T_b}{(\Delta T_b)_0} = \frac{\Delta P}{(\Delta P)_0} = \frac{\pi}{(\pi)_0} \quad (4)$$

where the quantities without subscript refer to electrolytes and those with subscript to non electrolytes.

## 1.5 How is the van't Hoff factor related to degree of ionization?

The van't Hoff factor is related to degree of ionization as follows:

$$i = 1 + \alpha(n - 1) \quad (5)$$

or

$$\alpha = \frac{i - 1}{n - 1} \quad (6)$$

where,  $\alpha$  = Degree of ionization/dissociation

$i$  = van't Hoff factor

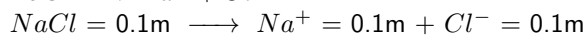
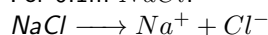
$n$  = Moles of ions obtained from ionization of 1 mole of electrolyte.

## 1.6 Which of the following solution will have higher freezing point depression and why?

i. 0.1m  $\text{NaCl}$

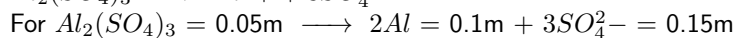
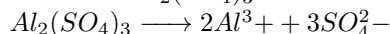
ii. 0.05m  $\text{Al}_2(\text{SO}_4)_3$

For 0.1m  $\text{NaCl}$ :



Total particles in solution = 0.2 mol

For 0.05m  $\text{Al}_2(\text{SO}_4)_3$



Total particles in solution = 0.25 mol

$\text{Al}_2(\text{SO}_4)_3$  solution contains more number of particles than  $\text{NaCl}$  solution. Hence,  $\text{Al}_2(\text{SO}_4)_3$  solution has maximum  $\Delta T_f$

Therefore, the freezing point depression of 0.05m  $\text{Al}_2(\text{SO}_4)_3$  solution will be higher than 0.1 m  $\text{NaCl}$  solution.

## 1.7 State Raoult's law for a solution containing a nonvolatile solute

The Raoult's law states that, "the vapour pressure of solvent over the solution is equal to the vapour pressure of pure solvent multiplied by its mole fraction in the solution."

**1.8 What is the effect on the boiling point of water if 1 mole of methyl alcohol is added to  $1\text{dm}^3$  of water? Why?**

1. When 1 mole of methyl alcohol is added to  $1\text{dm}^3$  of water, the boiling point of water decreases.
2. Methyl alcohol is a volatile liquid. Therefore, it increases the vapour pressure of a solution at given temperature. Hence, the solution boils at lower temperature.

**1.9 Which of the four colligative properties is most often used for molecular mass determination? Why?**

1. Among the four colligative properties, osmotic pressure is most often used for molecular mass determination.
2. Osmotic pressure is much larger and therefore more precisely measurable property than the colligative properties.

## **2 Two/Three Mark Questions**

**2.1 How vapour pressure lowering is related to a rise in the boiling point of solution**

1. At the boiling point of a liquid, its vapour pressure is equal to 1 atm.
2. In order to reach boiling point, the solution and solvent must be heated to a temperature at which their respective vapour pressures attain 1atm.
3. At any given temperature the vapour pressure of a solution is lower than of pure solvent. Hence, the vapour pressure of solution needs a higher temperature to reach 1atm than that of needed for vapour pressure of solvent.

Therefore, vapour pressure lowering causes a rise in the boiling point of a solution.

**2.2 What are isotonic and hypertonic solutions?**

**i. Isotonic Solutions**

Two or more solutions having the same osmotic pressure are said to be isotonic solutions.

e.g For example, 0.1M urea solution and 0.1M sucrose solution are isotonic because their osmotic pressure are equal. Such solutions have the same molar concentrations but different concentrations in g/L. If these solutions are separated by a semipermeable membrane, there is no flow of solvent in either direction.

**ii. Hypertonic Solution**

If two solutions have unequal osmotic pressure, the more concentrated solution with higher osmotic pressure is said to be the hypertonic solution.

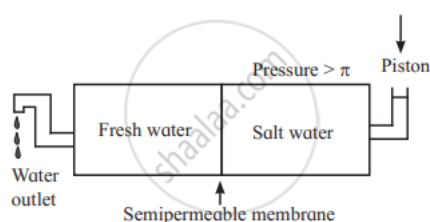
e.g For example, if osmotic pressure of sucrose solution is higher than that of urea solution, the sucrose solution is hypertonic to urea solution.

### 2.3 A solvent and its solvent containing a nonvolatile solute are separated by a semipermeable membrane. Does the flow of solvent occur in both directions? Comment giving a reason.

1. When a solution and pure solvent or two solutions of different concentrations are separated by a semipermeable membrane, the solvent molecules pass through the membrane.
2. The passage of solvent molecules through the semipermeable membrane takes place in both directions, since the solvent is on both sides of membrane.
3. However, the rate of passage of solvent molecules into solution or from a more dilute solution to more concentrated solution is found to be greater than the rate in reverse direction.
4. This is favorable since the vapour pressure of solvent is greater than that of solution.

### 2.4 Explain reverse osmosis.

1. If a pressure is larger than the osmotic pressure is applied to the solution side, then pure solvent from the solution passes into pure solvent side through the semipermeable membrane. This phenomenon is called reverse osmosis.
2. For example, consider fresh water and salt water separated by a semipermeable membrane. When the pressure larger than the osmotic pressure of solution is applied to the solution, pure water from salty water passes into fresh water through the membrane. Thus, the direction of osmosis can be reversed by applying a pressure larger than the osmotic pressure.
3. The schematic set up for reverse osmosis is as follows:



### 2.5 How molar mass of solute is determined by osmotic pressure measurement?

1. For very dilute solutions, the osmotic pressure follows the equation,

$$\pi = \frac{n_2 RT}{V} \quad (7)$$

2. If the mass of solute in V litres of solution is W<sub>2</sub> and its molar mass is

$$M_2, \text{ then } n_2 = \frac{W_2}{M_2} \quad (8)$$

Substituting the value of  $n_2$  in equation (1), we get

$$\pi = \frac{W_2 RT}{M_2 V} \quad (9)$$

$$\therefore M_2 = \frac{W_2 RT}{\pi V} \quad (10)$$

This formula can be used for the calculation of molar mass of nonionic solute (i.e nonelectrolytes) by osmotic pressure measurement.

## 2.6 Why vapour pressure of a solvent is lowered by dissolving a nonvolatile solute into it?

1. Vapour pressure of a liquid depends on the ease with which the molecules escape from the surface of liquid.
2. When a nonvolatile solute is dissolved in a solvent, some of the surface molecules of the solvent are replaced by nonvolatile solute molecules. These solute molecules do not contribute to vapour above the solution.
3. Thus, the number of solvent molecules available for vapourization per unit surface of the pure solvent.
4. As a result the solvent molecules at the surface of solution vapourize at a slower rate than pure solvent. This results in lowering of vapour pressure.

## 2.7 Using Raoult's law, how wil you show that $P_1^0 x_2$ ? Where, $x_2$ is the mole fraction of solute in the solution and $P_1^0$ vapour pressure of pure solvent.

1. Raoult's law expresses the quantitative relationship between vapour pressure of solution and vapour pressure of the solvent.
2. In soluitions of nonvolatile solutes, the law is applicable only to the volatile solvent.
3. The law states that, "the vapour pressure of solvent over the solution is equal to vapour pressure of pure solvent.
4. The law states that, "the vapour pressure of solvent over the solution is equal to the vapour pressure of pure solvent multiplied by its mole fraction in the solution."
5. Suppose that for a binary solution containing solvent and one nonelectrolytes solute,  $P_1$  is the vapour pressure of solvent over the solution,  $x_1$  and  $x_2$  are the mole fractions of solvent and solute, respectively and  $P_1^0$  is the vapour pressure of pure solvent, then  $P_1 = P_1^0 x_1$
6. Since,  $x_1 = 1 - x_2$ ,

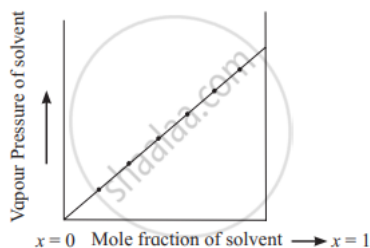
$$P_1 = P_1^0 x_1 = P_1^0 (1 - x_2) = P_1^0 - P_1^0 x_2 \quad (11)$$

$$\therefore P_1^0 - P_1 = P_1^0 x_2 \quad (12)$$

$$\therefore \Delta P = P_1^0 x_2 (\because \Delta P \text{ is the lowering of vapour pressure}) \quad (13)$$

Note : A plot of  $P_1$  versus  $x_1$  is a straight as shown below.

**Variation of vapour pressure of solution with mole fraction of solvent**



## 2.8 While considering boiling point elevation and freezing point of depression a solution concentration is expressed in molality and not in molarity. Why?

1. In boiling point elevation and freezing point depression, we deal with the systems whose temperature is not constant.
2. We cannot express the concentration of the solution in molarity because it changes temperature but whereas molality is temperature independent.

Hence, while considering boiling point elevation and freezing point depression a solution concentration is expressed in molality and not in molarity.

## 2.9 Derive the relationship between the degree of dissociation of an electrolyte and van't Hoff factor.

1. The weak electrolytes involve the concept of degree of dissociation ( $\alpha$ ) that changes the van't Hoff factor.
2. Consider an electrolyte  $A_xB_y$  that dissociates in aqueous solution as

|                |   |                          |                          |
|----------------|---|--------------------------|--------------------------|
|                | $A_xB_y \rightleftharpoons xA^{y+} + yB^{x-}$ |                          |                          |
| Initially      | 1mol  | 0                        | 0                        |
| At equilibrium | $(1 - \alpha)\text{mol}$                      | $(x \alpha \text{ mol})$ | $(y \alpha \text{ mol})$ |

3. If  $\alpha$  is the degree of dissociation of electrolyte, then the moles of cations are  $x\alpha$  and those of anions are  $y\alpha$  equilibrium. We have dissolved just 1 mol of electrolyte dissociates and  $(1 - \alpha)$  mol remains undissociated at equilibrium.

Total moles after dissociation =

$$(1 - \alpha) + (x\alpha) + (y\alpha) \quad (14)$$

$$= 1 + \alpha(x + y - 1) \quad (15)$$

$$= 1 + \alpha(n - 1) \quad (16)$$

Where,  $n = x + y$  = moles of ions obtained from dissociation of 1 mole of electrolyte.

4. The van't Hoff factor gives as

$$i = \frac{\text{actual moles of particles in solution after dissociation}}{\text{moles of formula units dissolved in solution}} \quad (17)$$

$$= \frac{1 + \alpha(n - 1)}{1} \quad (18)$$

Hence,  $i = 1 + \alpha(n - 1)$  or  $\alpha = \frac{i-1}{n-1}$

## 2.10 What is the effect of temperature on solubility of solids in water? Give examples.

1. The effect of temperature on solubility of a substance depends on enthalpy of solution.
  - (a) When the substance dissolves in water by an endothermic process, that is, with the absorption of heat, its adsorption of heat, its solubility increases with an increase in temperature.  
e.g KCl dissolves in water by endothermic process.
  - (b) On the other hand, when the substance dissolves in water by an exothermic process, that is, with the release of heat, its solubility decreases with an increase in temperature.  
e.g  $CaCl_2$  and  $Li_2SO_4 \cdot H_2O$  dissolves in water releasing heat.
2. It is important to understand that there is no direct correlation between solubility and exothermicity or endothermicity. For example, dissolution of  $CaCl_2$  in water is exothermic and that of  $NH_4NO_3$  is endothermic. However, the solubility of these substances increases with the temperature.

## 2.11 Explain with diagram that boiling point elevation in terms of vapour pressure lowering.

1. The vapour pressure of a solution and pure solvent are plotted as a function of temperature in the given diagram.
2. At any temperature, the vapour pressure of solution is lower than that of pure solvent. Hence, the vapour pressure- temperature curve of solution (CD) lies below that of solvent (AB)
3. The difference between two vapour pressure increases as temperature and vapour pressure increases as predicted by the following equation,

$$\Delta P = P_1^0 X_2 \quad (19)$$

4. The intersection of curve CD with line corresponding to 760mm is the boiling point solution. The similar intersection of the curve AB is the boiling point of pure solvent. It is clear from the diagram that the boiling point solution ( $T_b$ ) is higher than that of pure solvent ( $T_b^0$ )
5. At the boiling point of liquid its vapour pressure is equal to 1atm.
6. In order to reach the boiling point, the solution and solvent must be heated to a temperature at which their respective vapour pressure attain 1atm.
7. At any given temperature the vapour pressure of solution is lower than that of pure solvent. Hence, the vapour pressure of solution needs a higher temperature to reach 1atm than that for vapour pressure of solvent.
8. In other words, the solution must be heated to higher temperature to cause it to boil than pure solvent.

