

OSMOSIS AND OSMOTIC PRESSURE

Introduction of Osmosis and Osmotic Pressure

Osmosis

Osmosis is defined as the spontaneous flow of solvent molecules through semipermeable membrane from a dilute solvent to a solution or from a dilute to a concentrated solution.

Osmotic pressure (π)

The hydrostatic pressure developed as a result of osmosis is a measure of osmotic pressure of the solution.

or

The hydrostatic pressure built up on the solution which just stops the osmosis.

osmotic pressure = hydrostatic

pressure $\pi = h d g$

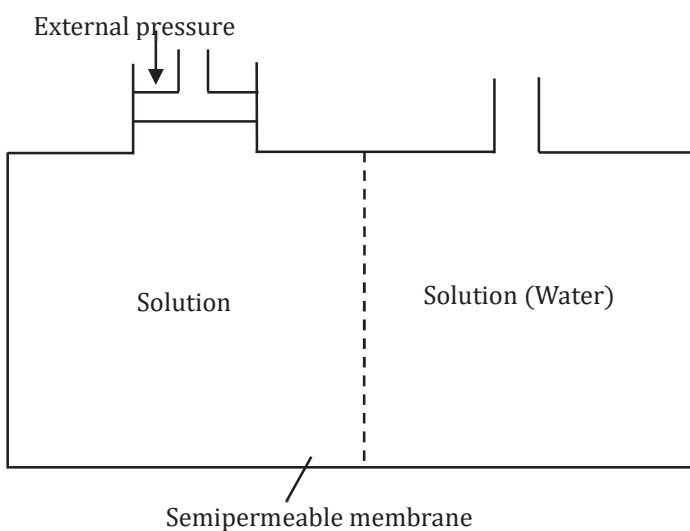
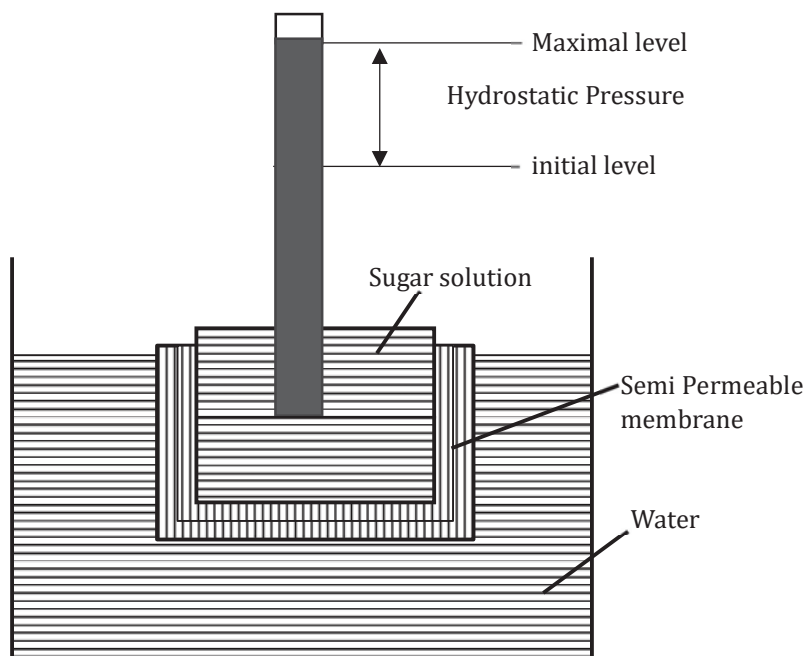
h = increase in level in the tube of unit cross section.

d = density of solution,

g = acceleration due to gravity

or

The osmotic pressure is the external pressure that needs to be exerted on the solution to halt the flow of the solvent into the solution through a semipermeable membrane.



Reverse osmosis and water purification

Reverse Osmosis

If an external pressure greater than the osmotic pressure is applied, the movement of solvent molecules can be directed from the solution toward the pure solvent, essentially reversing the usual osmotic direction. Reverse osmosis is employed for desalinating seawater to obtain fresh drinking water.

Ideal Solutions: An ideal solution is one that precisely follows Raoult's law under all concentrations and temperatures.

Key characteristics of an ideal solution include:

- (i) **Zero Volume Change of Mixing:** The volume change of mixing should be zero; $\Delta V_{\text{mix}} = 0$; $V_{\text{solvent}} + V_{\text{solute}} = V_{\text{solution}}$.
- (ii) **Zero Heat Change on Mixing:** The heat change during mixing should be zero; $\Delta H_{\text{mix}} = 0$ (neither absorbed nor evolved).
- (iii) **Absence of Chemical Reaction:** There should be no chemical reaction between the solvent and solute.
- (iv) **Non-Dissociation of Solute Molecules:** Solute molecules should not dissociate in the ideal solution.
- (v) **Non-Association of Solute Molecules:** Solute molecules should not associate in the ideal solution.
- (vi) **Adherence to Raoult's Law:** An ideal solution must comply with Raoult's law at all concentrations.

- Ex.:**
- (i) Benzene and toluene
 - (ii) Carbon tetrachloride and silicon tetra chloride.
 - (iii) n - Hexane and n - heptane
 - (iv) Ethylene dibromide and ethylene dichloride.

Non-Ideal solutions

Those solutions which do not obey Raoult's law are called non-ideal solutions.

For such solutions:

$$P_A \neq P_A^\circ X_A$$

$$P_B \neq P_B^\circ X_B$$

Non ideal solutions are formed when the components differ much in their structures and polarities.

$$\Delta H_{\text{mixing}} \neq \text{zero}$$

$$\Delta V_{\text{mixing}} \neq \text{zero}$$

Non ideal solutions show either positive or negative deviations from Raoult's law

Water Purification

Reverse Osmosis (RO) stands out as a pivotal water purification technology. The process involves pushing water through a semi-permeable membrane under pressure to eliminate contaminants, resulting in purified water suitable for consumption. RO is widely utilized, including in the desalination of seawater, making it a dependable source for obtaining potable water.

Key features and applications of RO include:

- The process effectively removes dissolved and suspended impurities, including bacteria.
- The semi-permeable membrane allows solvent molecules to pass through while preventing the passage of large ions or molecules through its pores.
- Polymer membranes, particularly cellulose acetate, are employed for desalinating seawater.
- Cellulose acetate, as a semi-permeable membrane, facilitates the passage of water molecules while remaining impermeable to impurities.
- RO technology finds diverse applications in the military, wastewater purification, the food industry, landfill leachate purification, and more.

Vant's Hoff's theory of dilute solution

The osmotic pressure (P or π) of a solution exhibits a direct proportionality to its concentration (C) at a constant temperature. The concentration of a solution containing one gram mole in V liters is equivalent to $1/V$.

thus $P \propto C$ (when temperature is constant)

$$\begin{array}{lcl} \text{or} & & 1 \propto \frac{P}{V} \\ & PV = \text{constant} & \text{or} \quad \pi V = \text{constant} \end{array}$$

Gay – Lussac – Van't Hoff law (Pressure - Temperature law)

Concentration remaining same, the osmotic pressure of a dilute solution directly proportional to its absolute temperature

$$\begin{array}{lcl} (T), \text{ i.e.,} & & P \propto T \\ \text{or} & & \frac{P}{T} = \text{constant} \\ \text{or} & & \frac{\pi}{T} = \text{constant} \end{array}$$

Combining the two laws, i.e., when concentration and temperature both are changing, the osmotic pressure will be given by:

$$\begin{array}{lcl} & & P \propto CT \\ \text{or} & & P = kCT \\ \text{or} & & P = k \cdot \frac{1}{V} \cdot T \quad \left(\text{since, } C = \frac{1}{V} \right) \\ \text{or} & & PV = ST \quad \text{or} \quad \pi V = ST \end{array}$$

S is called molar solution constant.

In this context, V represents the volume of the solution containing one gram mole of the solute. The calculated value for S is 0.082 liter atm $K^{-1} \text{ mol}^{-1}$, aligning with the value of R, the molar gas constant. If the solution contains n gram moles in V liters, the general equation would be modified as follows:

$$\begin{array}{lcl} & & PV = nST \\ \text{or} & & \pi V = nST \end{array}$$

Depression in freezing point

The freezing point of a liquid is the temperature at which the liquid and its solid state coexist in equilibrium. Another way to define it is as the temperature at which the liquid and solid states of a substance share the same vapor pressure. When a non-volatile, non-electrolyte is dissolved in a pure solvent, the vapor pressure of the solvent decreases. If T_0 is the freezing point of the pure solvent and $(T_f)_s$ is the freezing point of its solution, then,

$$(T_f)_s < T_0$$

The difference in the freezing point of pure solvent and solution is the depression of freezing point (ΔT_f). Thus, $T_0 - (T_f)_s = \Delta T_f$

Depression in freezing point is directly proportional to the lowering of vapour pressure of solution.

$$\Delta T_f \propto P^0 - P_s$$

from Raoult's law for dilute solution:

$$\begin{array}{lcl} \frac{P^0 - P_s}{P^0} & = & \frac{W_A}{m_A} \cdot \frac{m_B}{W_B} \\ \text{or} & & P^0 - P_s = \frac{W_A}{m_A} \cdot \frac{m_B}{W_B} \cdot P \end{array}$$

for the pure solvent, P^0 and m_B are constant. therefore –

$$\begin{array}{lcl} P^0 - P_s & \propto & \frac{W_A}{m_A W_B} \\ \text{or} & & \Delta P \propto \frac{W_A}{m_A W_B} \propto \Delta T \\ & & \Delta T_f = K \frac{W_A}{m_A W_B} \end{array}$$

Where K is a constant, called depression constant.

When $\frac{W_A}{m_A} = 1$ (one mole of solute)

And $w_B = 1 \text{ g.}$

Then $\Delta T_f = K$

If $\frac{W_A}{m_A} = 1$ and $w_B = 100 \text{ g}$

Then, $\Delta T_f = \frac{K}{100} = K'$

K' is called molecular depression constant. It is defined as the depression of freezing point produced when 1 mole of the solute is dissolved in 100 g of the solvent.

Thus $K' = 100 K$

So, $\Delta T_f = \frac{100K' \times W_A}{m_A \times W_B}$

If $\frac{W_A}{m_A} = 1$ and $w_B = 1000 \text{ g}$

Then $\Delta T_f = \frac{K}{1000} = K_f$

K_f is called molal depression constant.

K_f is defined as the depression of freezing point produced when 1 mole of solute is dissolved in 1000 g of the solvent.

or $\Delta T_f = \frac{1000K_f \times W_A}{m_A \times W_B}$

or $\Delta T_f = \text{molality} \times K_f$

K_f is characteristic of a particular solvent and can be calculated from the thermodynamical relationship

$$K_f = \frac{0.002T_f^2}{L_f}$$

Where, T_f is the freezing point of solvent in absolute scale and L_f the latent heat of fusion in calories per gram of the solvent.

For water, $K_f = \frac{0.002 \times (273)^2}{80} = 1.86$

the molal depression constant for some common solvents are given in the following table

Solvent	F.P.(°C)	Molal Depression Solvents
Water	0.0	1.86
Ethyl alcohol	- 114.6	1.99
Chloroform	- 63.5	4.70
Carbon tetra chloride	- 22.8	29.80
Benzene	5.5	5.12
Camphor	179.0	39.70