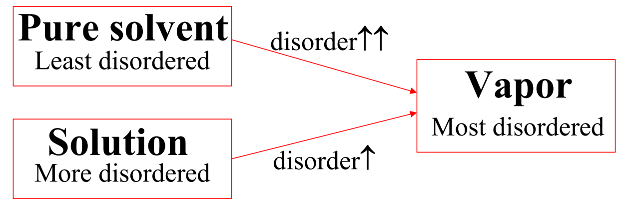
13.5 Colligative Properties of Solutions

- **Colligative properties** – depend on the concentration of solute particles but not on their chemical identity
  - The concentration of solute particles depends on the amount of dissolved solute as well as on its ability to dissociate to ions in solution
    - **Strong electrolytes** – dissociate completely (soluble salts, strong acids and bases)
    - **Weak electrolytes** – dissociate partially (weak acids and bases)
    - **Nonelectrolytes** – do not dissociate (many organic compounds)

Nonvolatile Nonelectrolyte Solutions

– No dissociation; no vapor pressure (glucose, sugar, …)

- **Vapor pressure lowering (*ΔP*)** – the vapor pressure of the solvent over the solution (P_{solv}) is always lower than the vapor pressure over the pure solvent (P°_{solv}) at a given temperature



⇒ The solution has a lesser tendency to vaporize so its vapor pressure is lower

➢**Raoult's Law** – the vapor pressure of the solvent over the solution is directly proportional to the mole fraction of the solvent

– Followed strictly at all concentrations only by **ideal solutions**

$$P_{solv} = X_{solv} P^{\circ}_{solv}$$

$$X_{solv} \le 1 \quad \Rightarrow \quad P_{solv} \le P^{\circ}_{solv}$$

$$X_{solv} = 1 - X_{solute} \quad \Rightarrow \quad P_{solv} = (1 - X_{solute}) P^{\circ}_{solv}$$

$$P_{solv} = P^{\circ}_{solv} - X_{solute} P^{\circ}_{solv} \;\rightarrow\; P^{\circ}_{solv} - P_{solv} = X_{solute} P^{\circ}_{solv}$$

$$\Delta P = X_{solute} P^{\circ}_{solv}$$

⇒ The vapor pressure lowering is directly proportional to the mole fraction of the solute

Example: The vapor pressure of water over a solution of a nonelectrolyte is **16.34 torr** at 20°C. Determine the mole fraction of the solute, if the equilibrium vapor pressure of water at 20°C is **17.54 torr**.

→ $P_{solv} = 16.34$ torr $\quad P^{\circ}_{solv} = 17.54$ torr

→ $X_{solute} = ?$

$$X_{solute} = \frac{\Delta P}{P^{o}_{solv}} = \frac{(17.54 - 16.34)\,\text{torr}}{17.54\,\text{torr}} = 0.0684$$

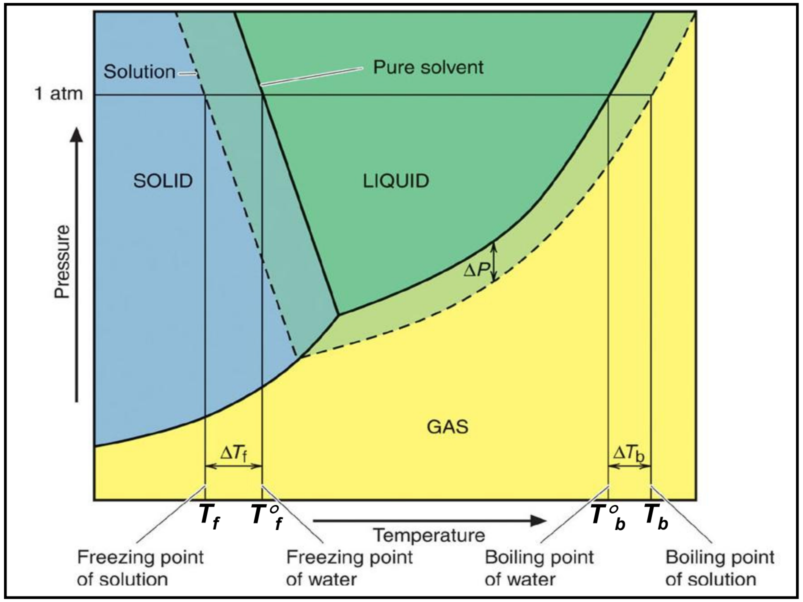
– Most real (**non-ideal**) solutions behave as ideal at low concentrations (less than 0.1 m for nonelectrolytes and less than 0.01 m for electrolytes)

- **Boiling point elevation (ΔT_b) and freezing point depression (ΔT_f)**
  - The **solution boils at a higher temperature** compared to the pure solvent (the solution has lower vapor ***P*** so it needs higher ***T*** to boil)
  - The **solution freezes at a lower temperature** compared to the pure solvent

Solid Least disordered → disorder↑ → **Pure solvent** More disordered

Solid Least disordered → disorder↑↑ → **Solution** Most disordered

⇒ The solution has a greater tendency to melt so its melting (freezing) point is lower



$\Delta T_b = T_b - T^\circ_b > 0 \quad \rightarrow \quad \Delta T_b = k_b m$

$\Delta T_f = T^\circ_f - T_f > 0 \quad \rightarrow \quad \Delta T_f = k_f m$

→ k_b – boiling point elevation constant →

→ k_f – freezing point depression constant → Depend on the solvent

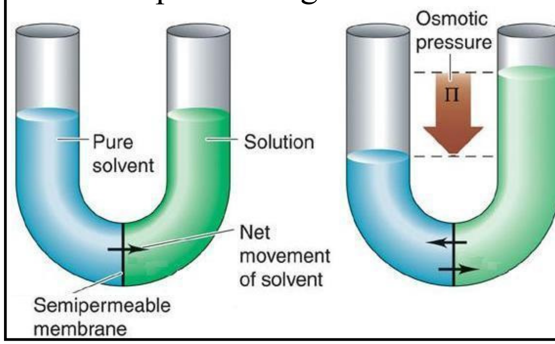
→ m – molality of solution

Example: What is the boiling point of a solution prepared by dissolving **12 g** of glucose (MW = 180 g/mol) in **55 g** of water? (For water, k_b**=0.512°C/m** and k_f**=1.86°C/m**)

$$12\text{ g gluc}\frac{1\text{ mol gluc}}{180\text{ g gluc}} = 0.067\text{ mol} \qquad m = \frac{0.067\text{ mol gluc}}{0.055\text{ kg water}} = 1.2\text{ m}$$

$$\Delta T_b = 0.512\frac{°\text{C}}{\text{m}} \times 1.2\text{ m} = 0.62°\text{C} \qquad T_b = 100 + 0.62 = \boxed{100.62°\text{C}}$$

- **Osmotic pressure (Π)**
  - **Osmosis** – the flow of solvent trough a semipermeable membrane from a less concentrated into a more concentrated solution
  - **Semipermeable membrane** – the solute particles can't pass through



➢The solvent tends to flow into the solution where the disorder is greater

– Π is the hydrostatic pressure necessary to stop the net flow of solvent caused by osmosis

$$\boxed{\Pi = MRT} \qquad \Pi = (n_{solute}/V_{soln})RT$$

→ ***M*** – molarity of solution
→ ***R*** – gas constant; ***T*** – temperature in **K**

- The equation is the equivalent of the ideal gas law (***P*** = ***nRT***/***V***) applied to solutions
  - Π is the pressure the solute would exert if it were an ideal gas occupying alone the volume of the solution
- Osmosis is essential for controlling the shape and size of biological cells and purifying blood through dialysis
- **Reverse osmosis** – reversing the flow by applying external pressure (used to purify sea water)

Example: What is the minimum pressure that must be applied in order to purify a **0.82 M** nonelectrolyte solution by reverse osmosis at **25°C**?

→ Calc. Π (the necessary pressure must be ≥ Π)

$$\Pi = MRT = \mathbf{0.82\,\frac{mol}{L} \times 0.08206\,\frac{L \cdot atm}{mol \cdot K} \times 298\,K}$$

$$\Pi = \boxed{\mathbf{20\ atm}}$$

→ This pressure is equivalent to a 200 meters (1/8 mile) tall water column!