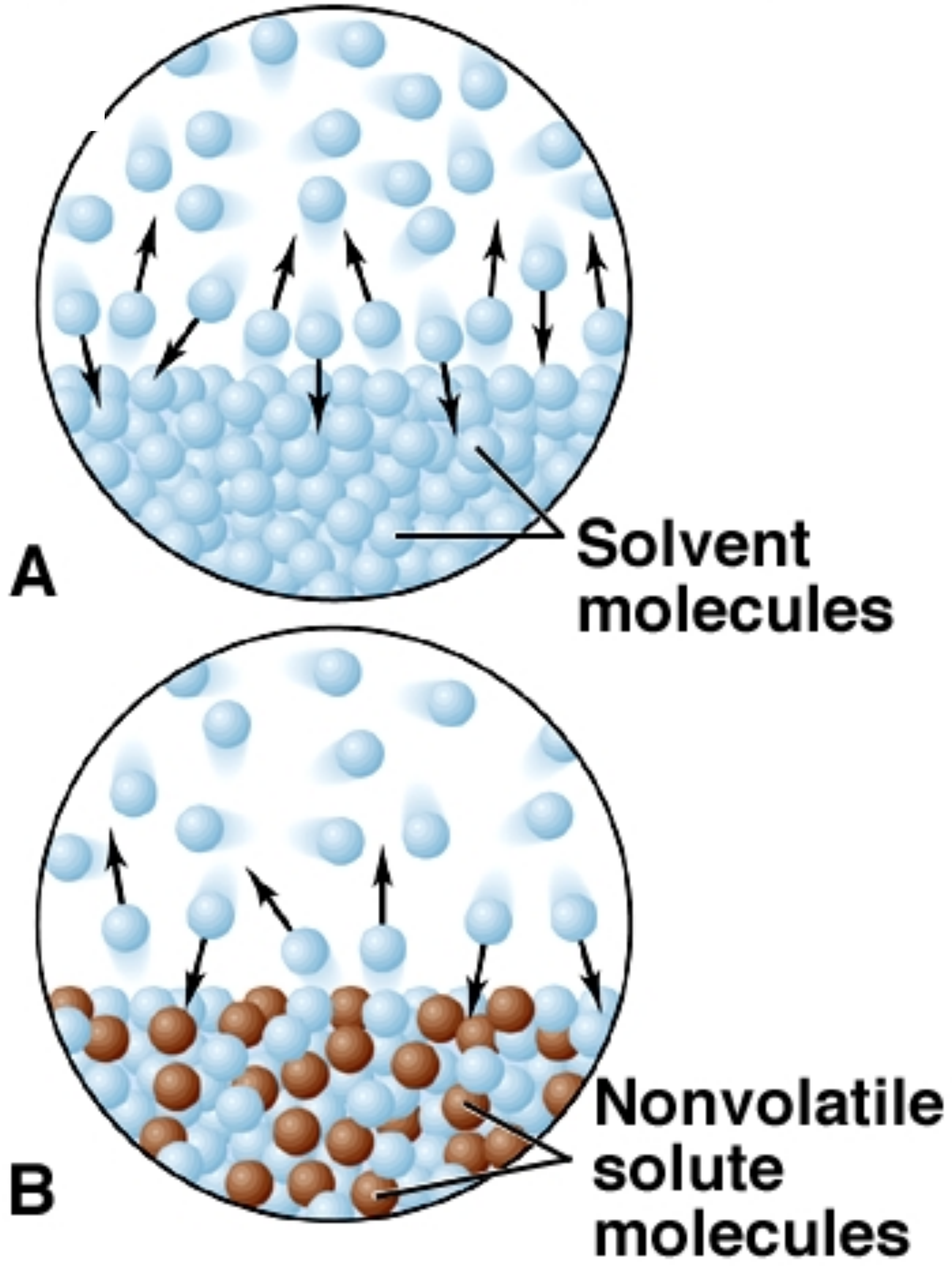
Colligative Properties

Colligative properties depend only on the number of solute particles in solution and not on the nature of the solute particles

1. **Vapor Pressure Lowering**
2. **Boiling Point Elevation**
3. **Freezing Point Depression**
4. **Osmotic Pressure**

Effect of Solute on Vapor Pressure of Solution

Vaporization occurs because of the tendency of a system to become more disordered. The solution is already more disordered than the pure solvent, therefore, fewer molecules vaporize in a given time.



$$P_{solvent} = X_{solvent} \cdot P^0_{solvent}$$

(in solution) (in solution)

$$X_{solvent} = 1 - X_{solute}$$

$$P_{solvent} = (1 - X_{solute}) \cdot P^0_{solvent}$$

$$P_{solvent} = P^0_{solvent} - X_{solute} \cdot P^0_{solvent}$$

$$P^0_{solvent} - P_{solvent} = X_{solute} \cdot P^0_{solvent}$$

$$\Delta P = X_{solute} \cdot P^0_{solvent}$$

↳ vapor pressure lowering

Calculate the vapor pressure lowering when 10.0 mL glycerol ($C_3H_8O_3$) is added to 500 mL water at 50°C. At this temp. the vapor pressure of pure water is 92.5 torr and its density is 0.988 g/mL. The density of glycerol is 1.26 g/mL

$$\text{moles}(C_3H_8O_3) = 10.0\,\text{mL} \cdot \frac{1.26\,g}{1\,\text{mL}} \cdot \frac{1\,\text{mol}}{92.09\,g} = 0.137\,\text{mol}$$

$$\text{moles}(H_2O) = 500\,\text{mL} \cdot \frac{0.988\,g}{1\,\text{mL}} \cdot \frac{1\,\text{mol}}{18.02\,g} = 27.4\,\text{mol}$$

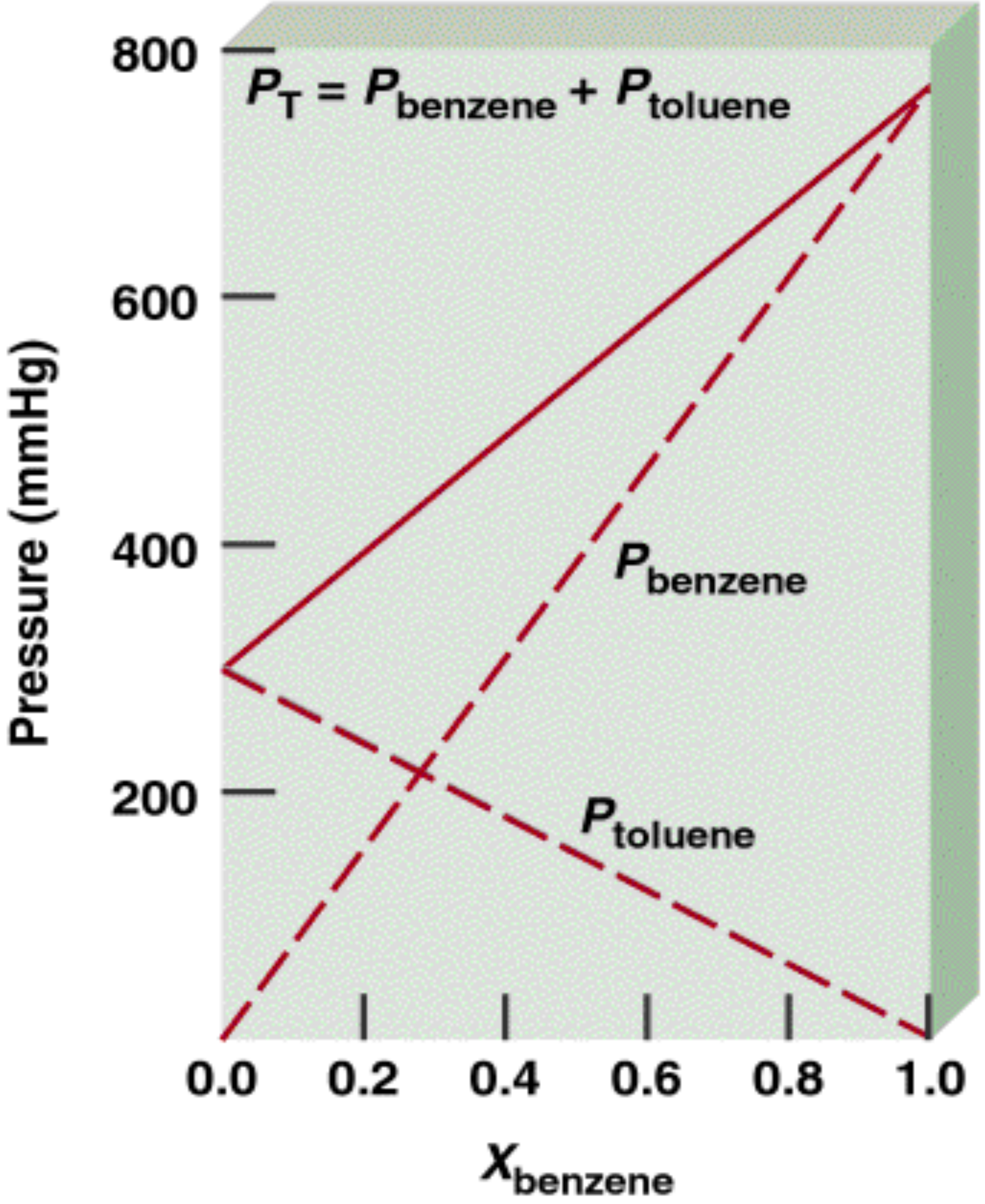
$$X_{glycerol} = \frac{0.137\,\text{mol}}{0.137\,\text{mol} + 27.4\,\text{mol}} = 0.00498$$

$$\underline{\underline{\Delta P}} = X_{solute} \cdot P^\circ_{solvent} = 0.00498 \cdot 92.5\,\text{torr} = 0.461\,\text{torr}$$

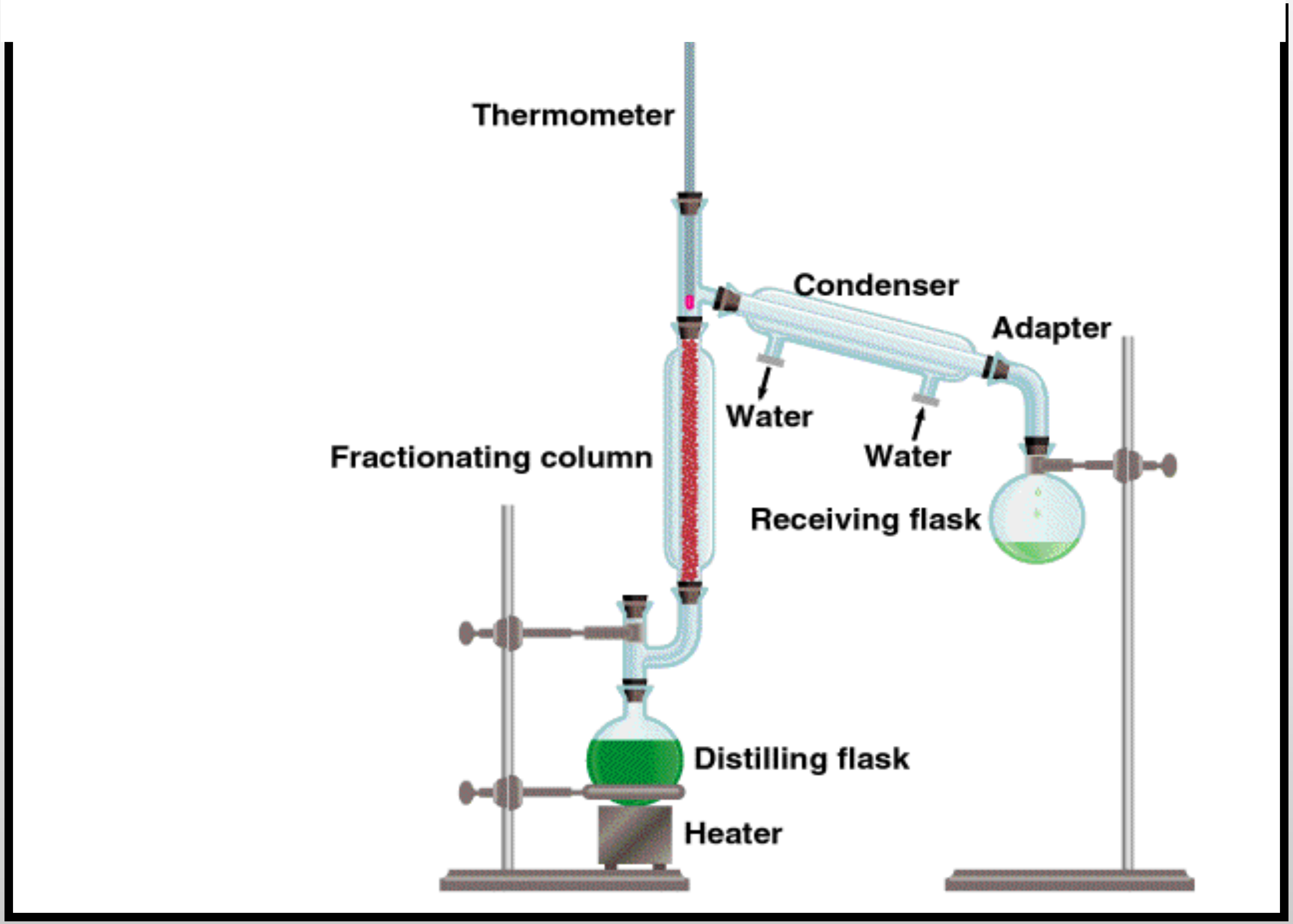
$$P_{solvent} = P^\circ_{solvent} \overset{!!}{-} \Delta P \Rightarrow P_{solvent} = 92.5\,\text{torr} - 0.461\,\text{torr} = 92.0\,\text{torr}$$

Vapor Pressure of Ideal Volatile Nonelectrolyte Solutions

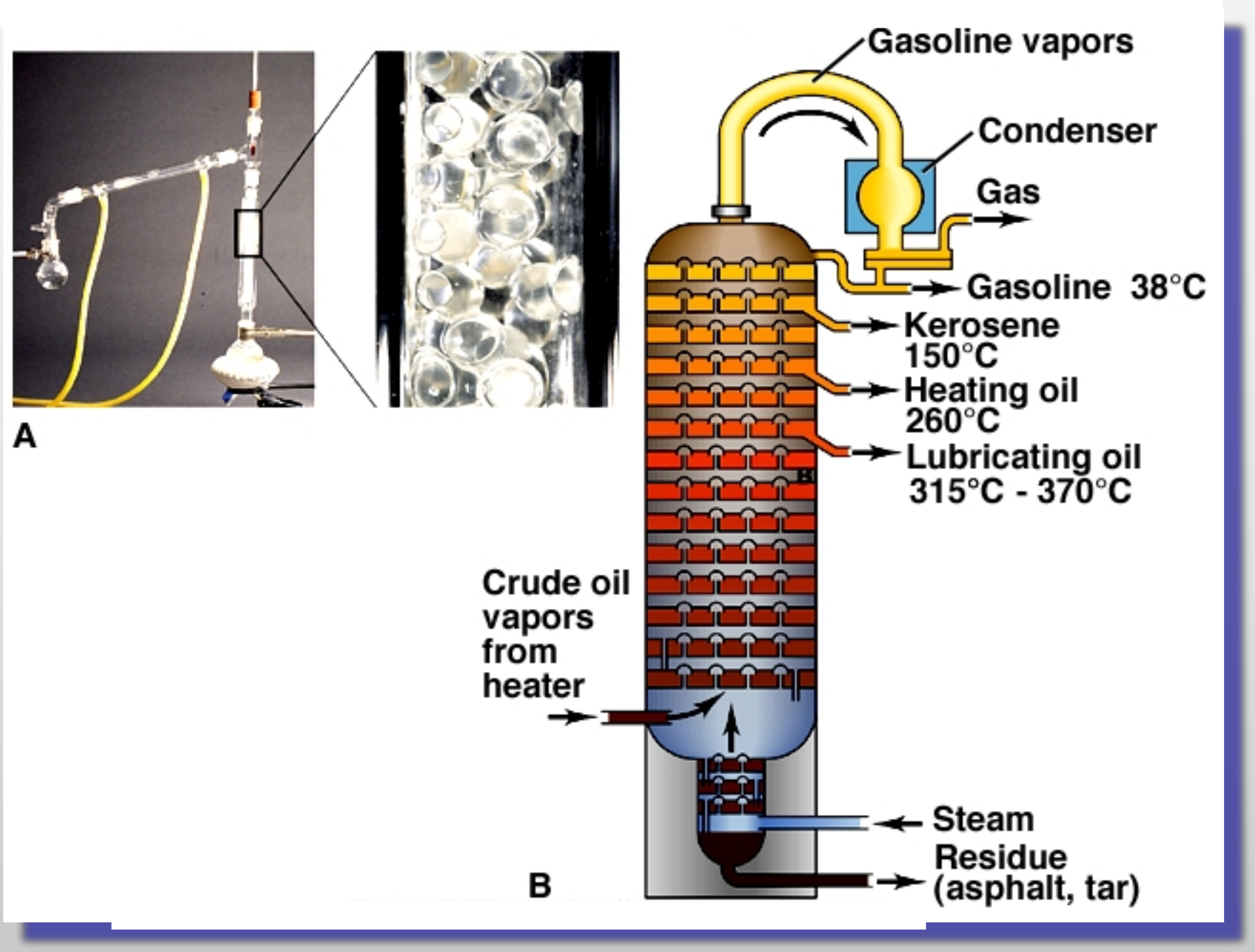
($X_{toluene} = 1 - X_{benzene}$)



Apparatus for Small Scale Fractional Destillation



Fractional Distillation of Crude Oil



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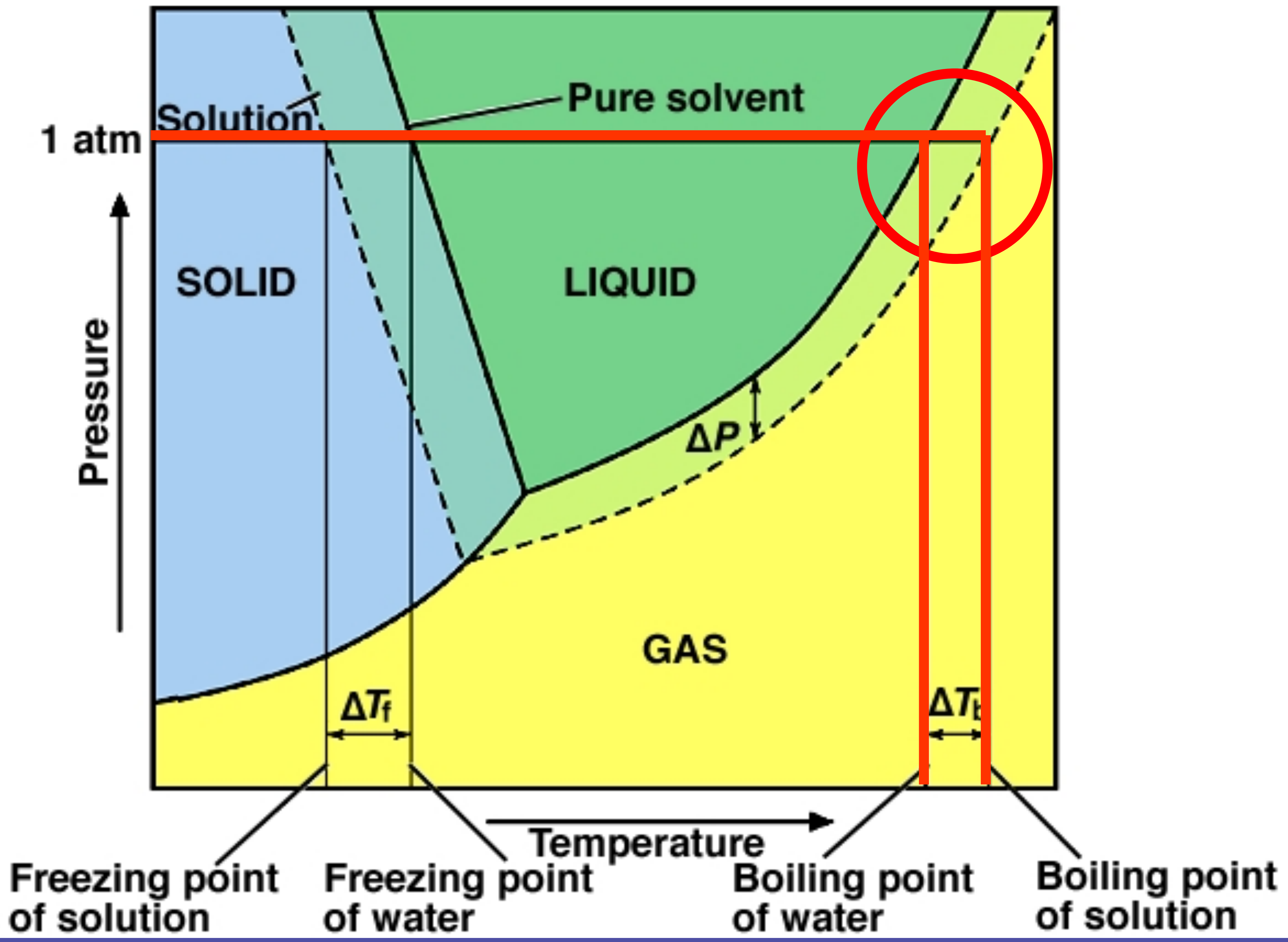
Phase Diagram of Solvent and Solution



Boiling Point Elevation

$$\Delta T_b = T_b - T_b^0$$

T_b: b.p. of solution

T_b^0: b.p. of pure solvent

$$\Delta T_b = k_b \cdot m$$

m: molality

k_b: molal boiling elevation constant

$$\text{molality} = \frac{\#\text{moles (solute)}}{\text{mass (solvent)}}$$

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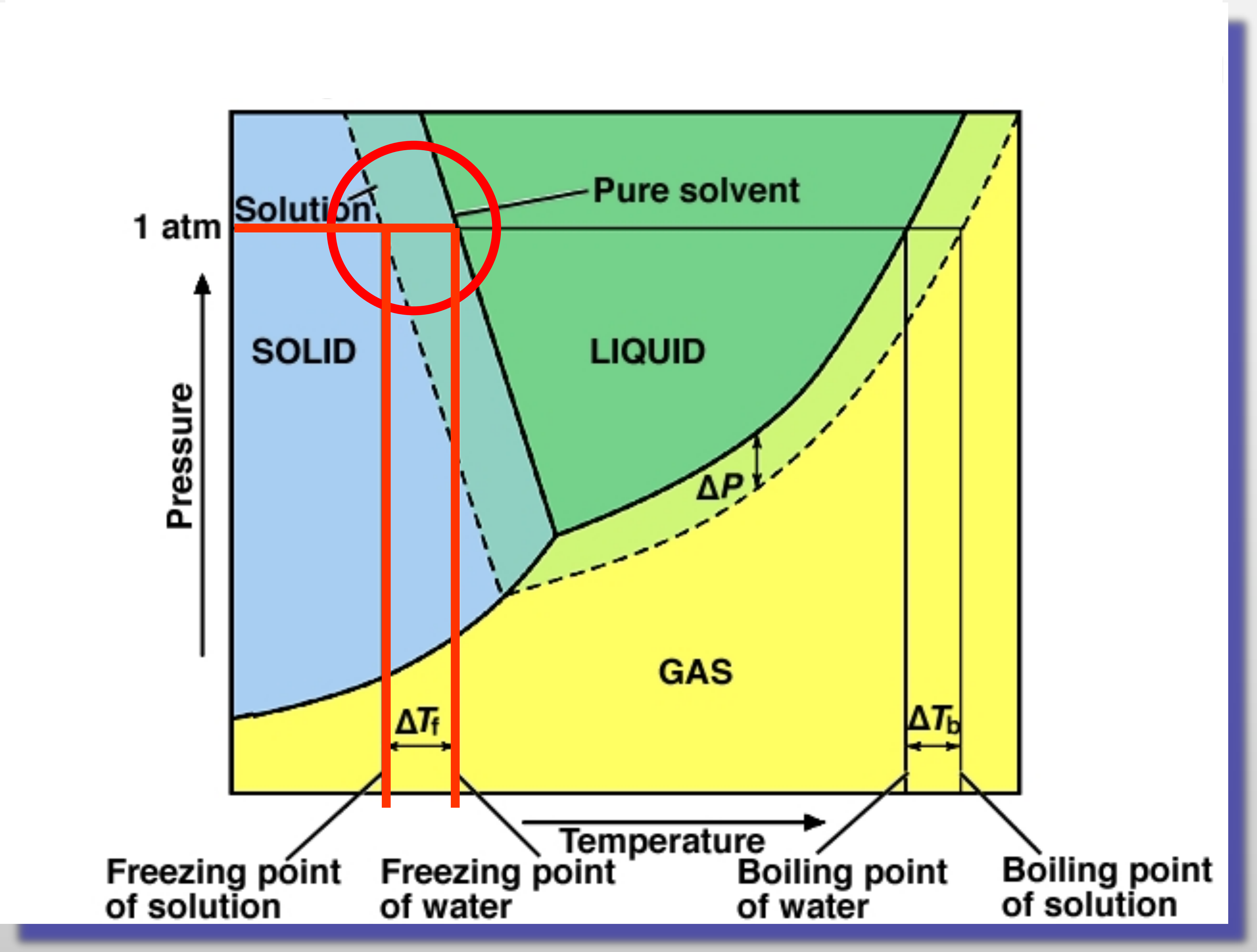


Freezing point depression

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

f.p. of pure solvent

freezing pt. of the solution

$$\Delta T_f = k_f \cdot m$$

molality

molal freezing depression constant

You add 1kg of the antifreeze ethylene glycol ($C_2H_6O_2$) to your car radiator, which contains 4450g H_2O. What are the b.p. and f.p. of the solution?

$K_b = 0.512°C/m$ $K_f = 1.85°C/m$

1. Calculate molality

$$\#\text{moles } (C_2H_6O_2) = 1.00\,kg \cdot \frac{1000\,g}{1\,kg} \cdot \frac{1\,mol}{62.07\,g} = 16.1\,mol$$

$$\text{molality} = \frac{16.1\,mol}{4450\,g \cdot \frac{1\,kg}{1000\,g}} = 3.62\,m$$

2. Boiling pt. elevation

$$\Delta T_b = K_b \cdot m$$

$$\Delta T_b = 0.512°C/m \cdot 3.62\,m = 1.85°C$$

$$T_b(\text{solution}) = 100°C \overset{!!}{+} 1.85°C = 101.85°C = 102°C$$

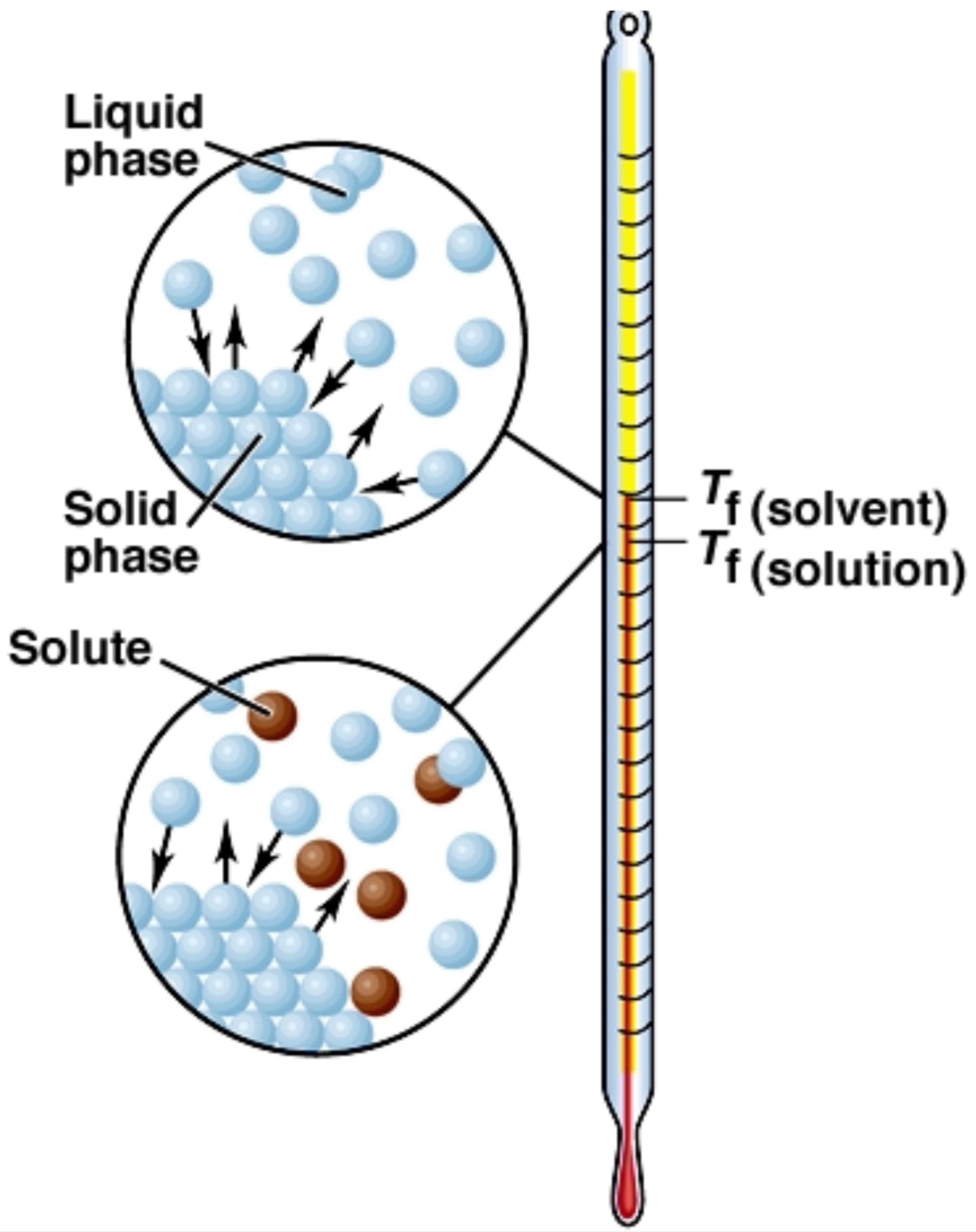
3. Freezing depression :

$$\Delta T_f = K_f \cdot m(C_2H_6O_2) = 1.85^\circ C/m \cdot 3.62\,m = 6.73^\circ C$$

$$T_f(\text{solution}) = T_f(\text{solvent}) - \Delta T_f$$

$$= 0^\circ C - 6.73^\circ C = -6.73^\circ C$$

Effect of Solute on the Freezing Point of a Solution



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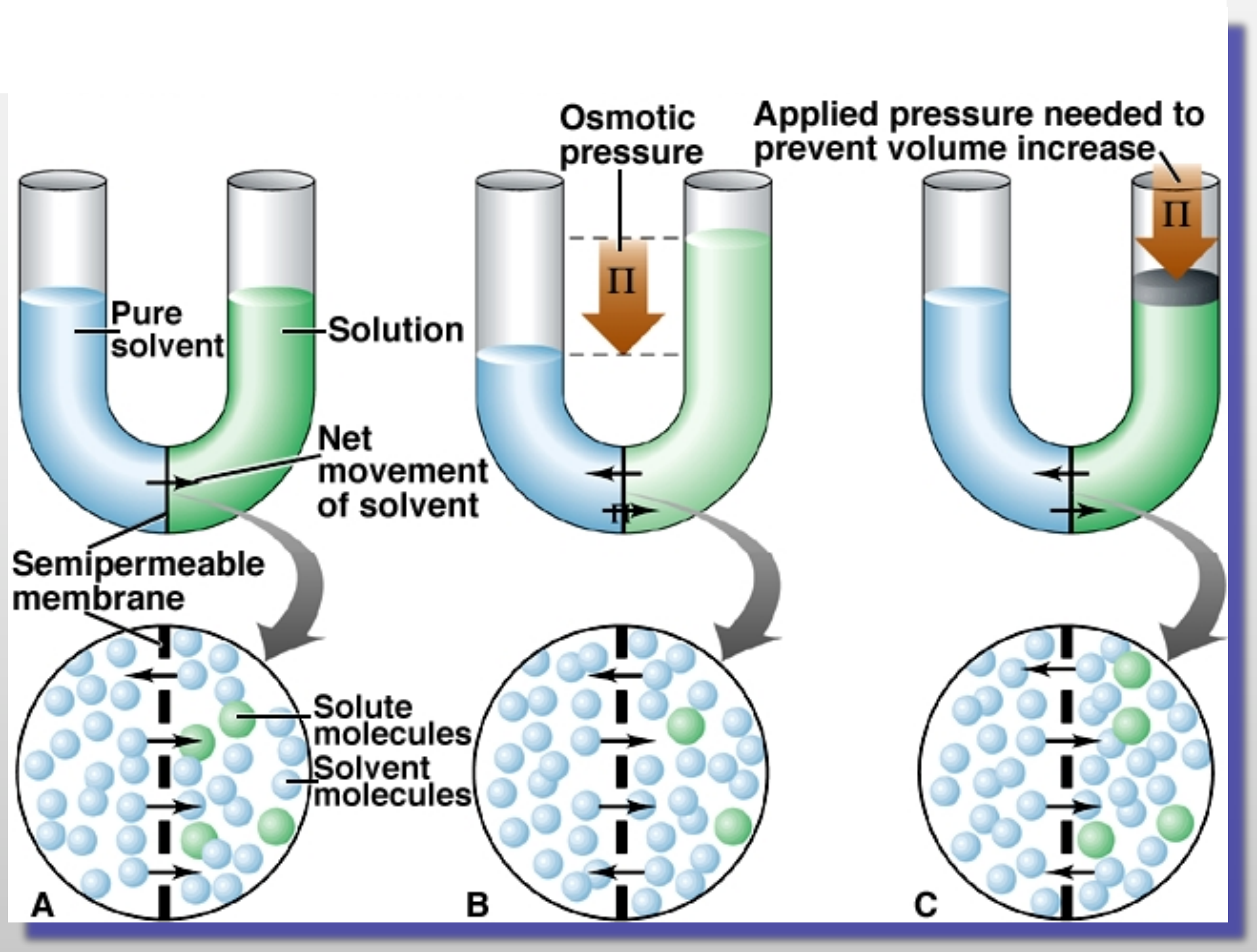
Development of Osmotic Pressure



Osmotic pressure: Pressure required to stop osmosis

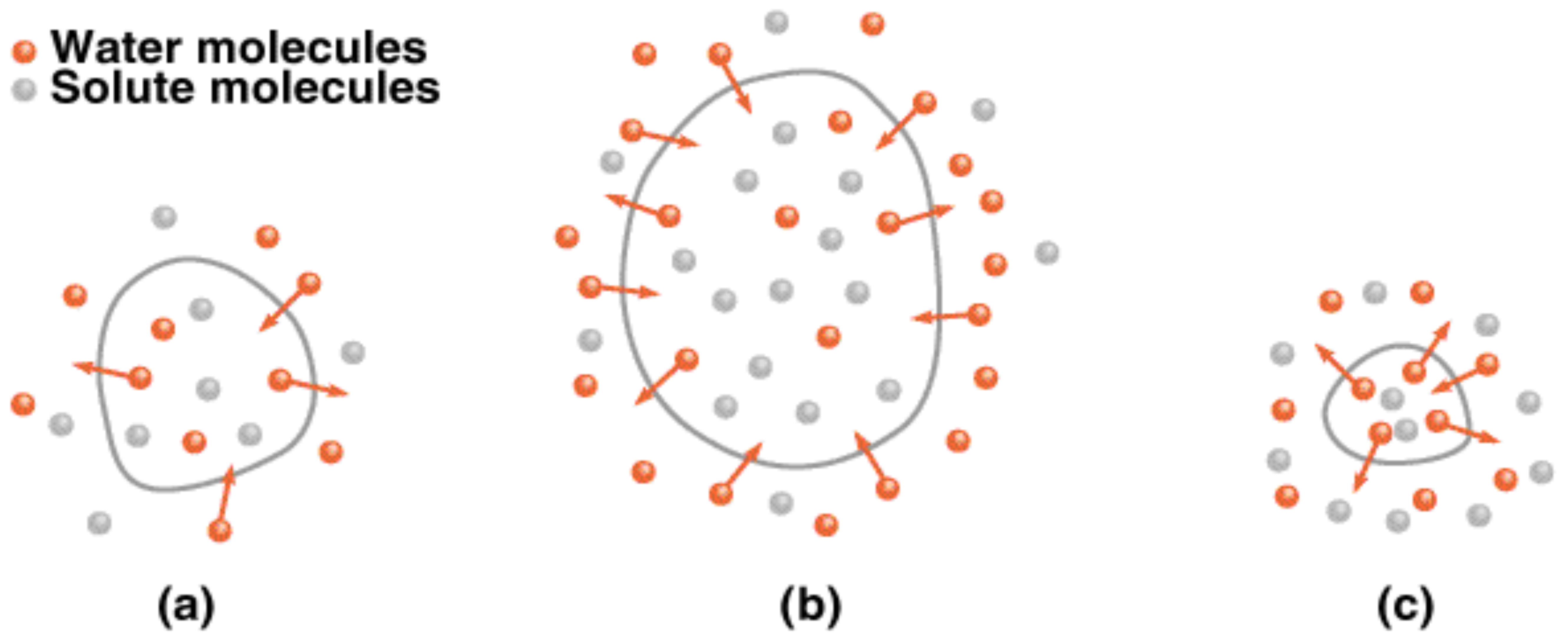
$$\Pi = MRT$$

M : molarity

R : $0.0821 \ \frac{L\,atm}{mol\,K}$

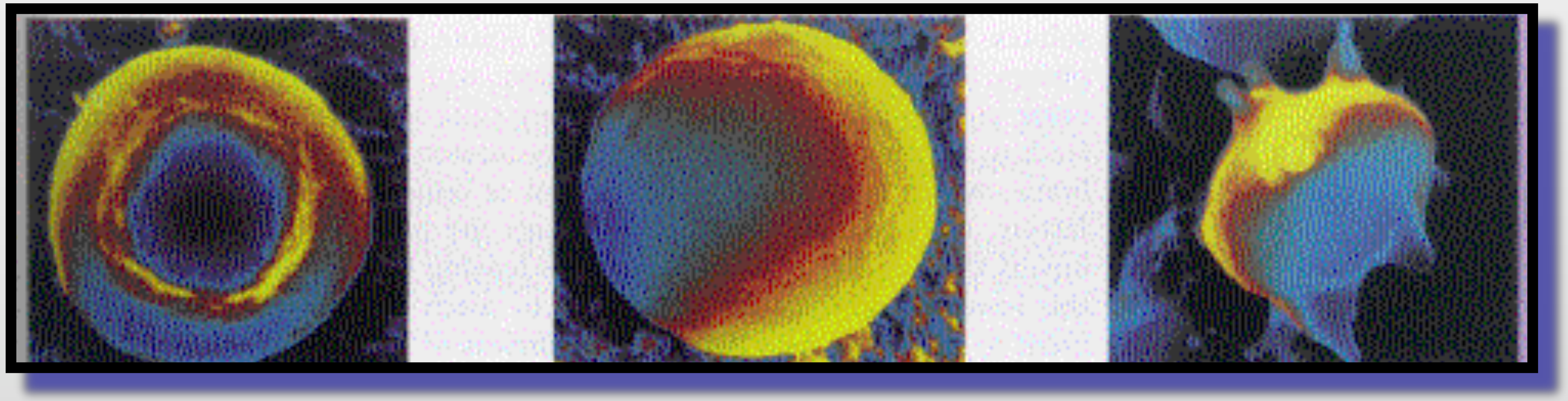
T : [K]

A Cell in an Isotonic Solution, a Hypotonic Solution, and a Hypertonic Solution



Erythrocytes in Solutions of Different Concentration

isotonic hypertonic hypotonic



Colligative properties and electrolyte solutions

$$\underset{1\,mol}{NaCl} \xrightarrow{H_2O} \underbrace{\underset{1\,mol}{Na^+(aq)} + \underset{1\,mol}{Cl^-(aq)}}_{2\,mol}$$

$$i\ (\text{van't Hoff factor}) = \frac{\text{actual number of particles after dissoc.}}{\text{number of formula units initially dissolved}}$$

$$\Delta T_b = i k_b m$$

$$\Delta T_f = i K_f m$$

$$\Pi = i MRT$$

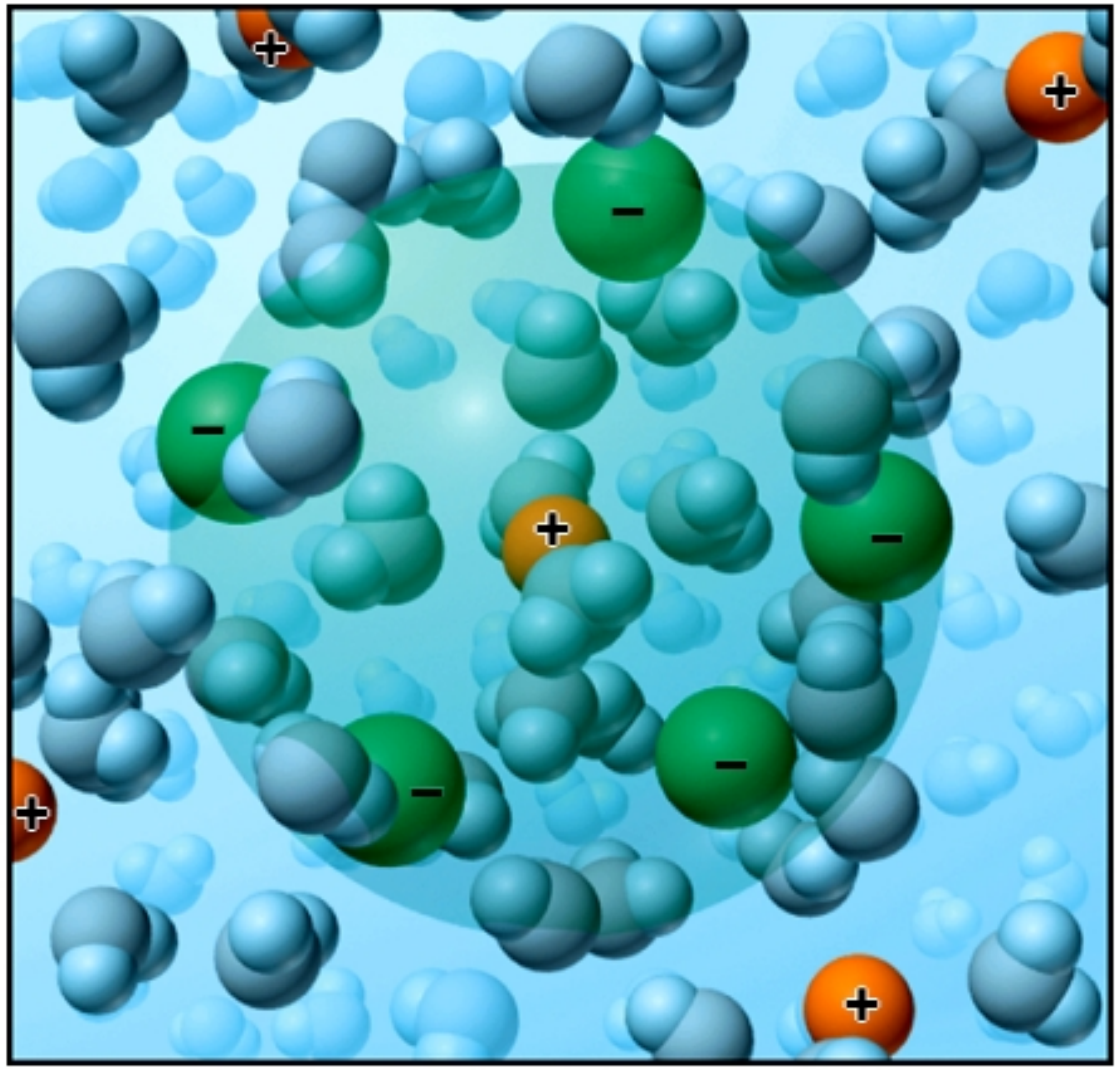
$NaCl \rightarrow Na^+(aq) + Cl^-(aq) \qquad i = 2$

$FeCl_3 \rightarrow Fe^{3+}(aq) + 3Cl^-(aq) \qquad i = 4$

$SrCl_2 \rightarrow Sr^{2+}(aq) + 2Cl^-(aq) \qquad i = 3$

Model for Nonideal Electrolyte Solutions

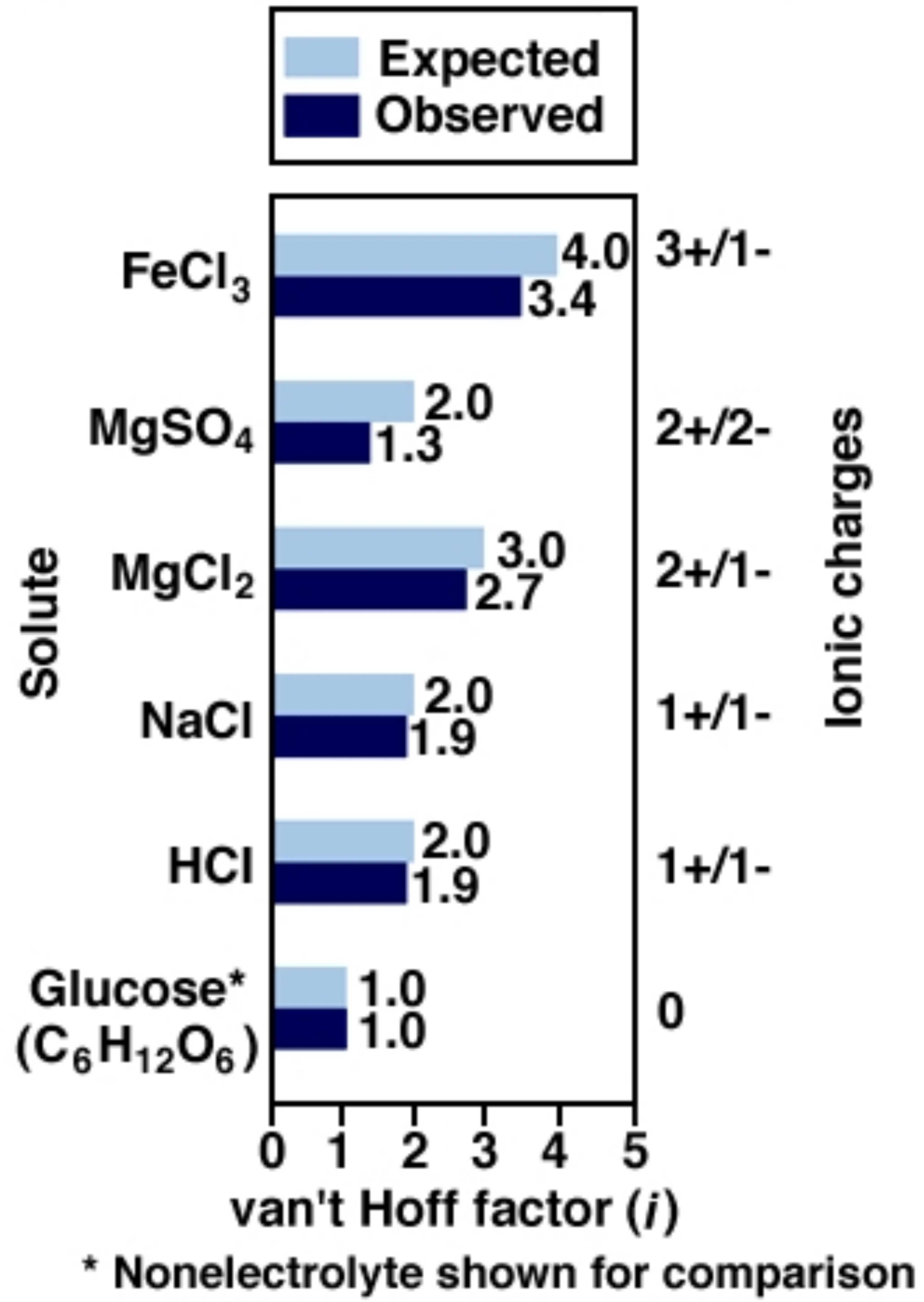
Hydrated anions cluster near cations, and vice versa. Since ions do not behave independently, their concentrations are effectively *less* than expected.



Nonideal Behavior of Electrolyte Solutions

$Mg^{2+} + SO_4^{2-}$

$Mg^{2+} + 2Cl^-$



$FeCl_3$:

$\Delta T_f = 6.21°C$ $\quad$ $0.982\ m$

$\Delta T_f = i K_f m$

$$i = \frac{\Delta T_f}{K_f \cdot m} = \frac{6.21°C}{1.86°C/m \cdot 0.982\ m} = 3.40$$

$i_{theoretical} = 4$

$i_{measured} = 3.40$