

Colligative Properties of Nonelectrolyte Solutions

Colligative Properties

Depends only on **number of particles** of a solute in solution and not on the nature of the solute

Vapor pressure lowering

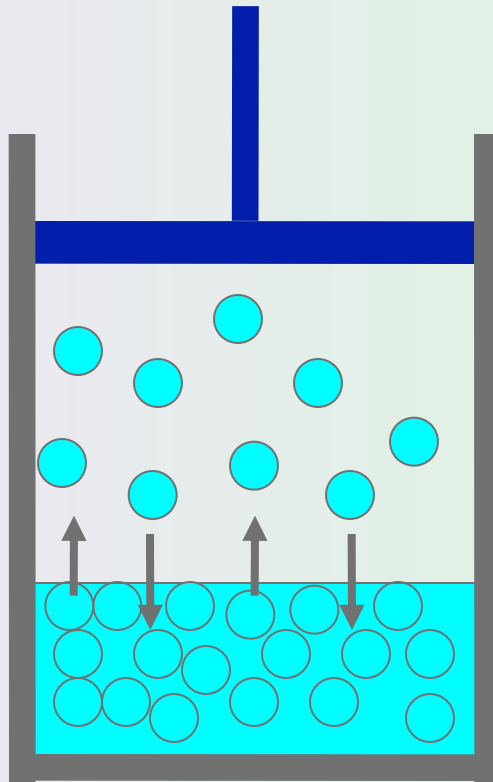
Boiling point elevation

Freezing-point depressing

Osmotic Pressure

Vapor Pressure

The pressure exerted by a vapor in equilibrium with its liquid



volatile

having a measurable vapor pressure

nonvolatile

**Does not have a measurable vapor
pressure**

Vapor pressure lowering

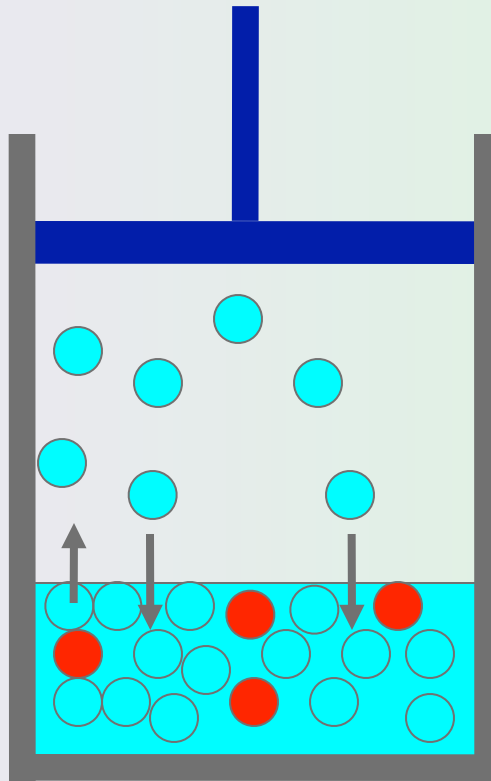
The vapor pressure of a solution containing a **nonvolatile** solute is always less than that of the pure solvent.

the nonvolatile solute lowers the number of volatile solvent molecules at the surface of the solution

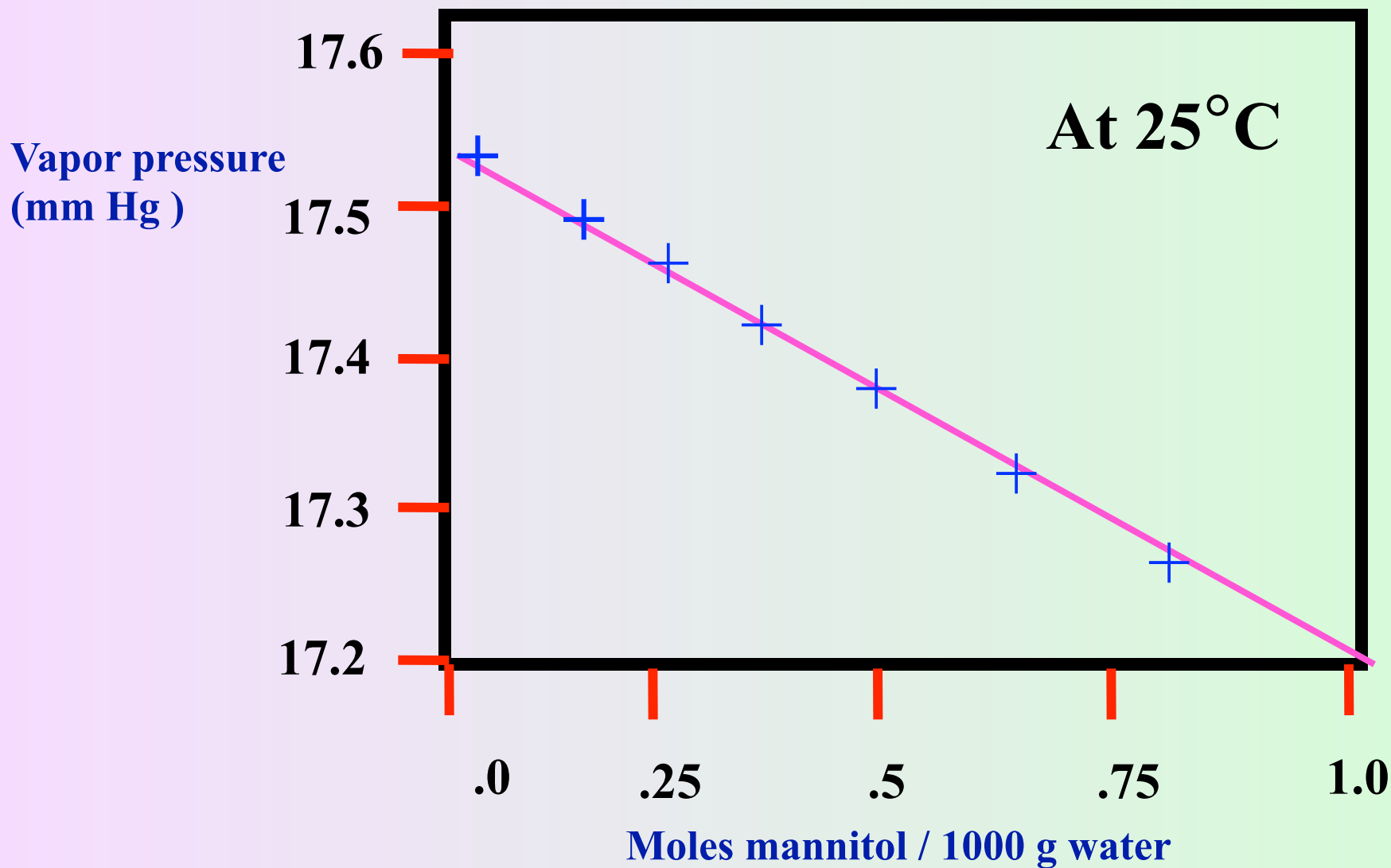
less opportunity for solvent molecules to escape into the gas phase

Vapor pressure lowering

The solute dilutes the solvent



Vapor pressure of water-mannitol solutions



Raoult's Law

The vapor pressure of the solution is proportional to the mole fraction of the **solvent** in the solution.

$$P_{\text{solution}} = (X_{\text{solvent}}) (P^{\circ}_{\text{solvent}})$$

Vapor pressure
solution

mole fraction of
the solvent

Vapor pressure
of pure solvent

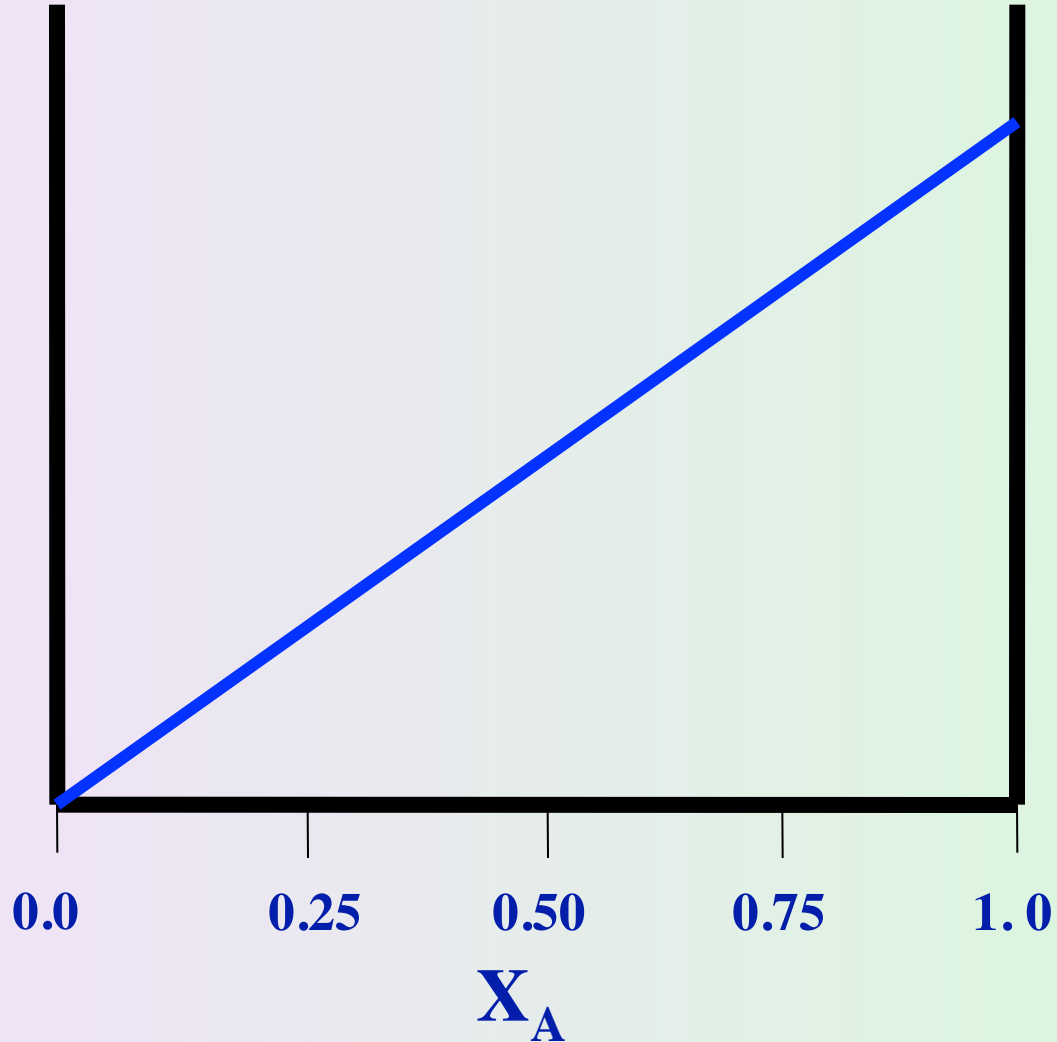
Raoult's Law represents an equation of a straight line

$$P_{\text{solution}} = X_{\text{solvent}} P^{\circ}_{\text{solvent}}$$

y = *x* *m* + *b* = 0

Ideal solution

Vapor
pressure



Example

Calculate the vapor pressure of a solution of 0.250 mol of sucrose in 1.100 mol of water at 50 ° C. The vapor pressure of pure water at 50 ° C is 92.5 torr.

$$X_A = \frac{1.100 \text{ mol H}_2\text{O}}{1.100 \text{ mol H}_2\text{O} + 0.250 \text{ mol sucrose}} = 0.815$$

$$P_A = X_A P_A^\circ$$

$$= (0.815) (92.5 \text{ torr}) = 75.4 \text{ torr}$$

Example

Adding 20g of urea to 125g of water at 25 ° C, a temperature at which water has a vapor pressure of 23.76 torr. The vapor pressure of the solution is 22.67 torr. Calculate the molar mass of urea.

$$X_{\text{H}_2\text{O}} = \frac{P_{\text{soln}}}{P^{\circ}\text{H}_2\text{O}} = \frac{22.67 \text{ torr}}{23.76 \text{ torr}} = 0.9541$$

$$125\text{g H}_2\text{O} \times \frac{1 \text{ mol H}_2\text{O}}{18\text{g H}_2\text{O}} = 6.94 \text{ mol H}_2\text{O}$$

$$X_{\text{H}_2\text{O}} = \frac{\text{mol H}_2\text{O}}{\text{mol H}_2\text{O} + \text{mol urea}} = \frac{6.94}{6.94 + \text{mol urea}} = 0.9541$$

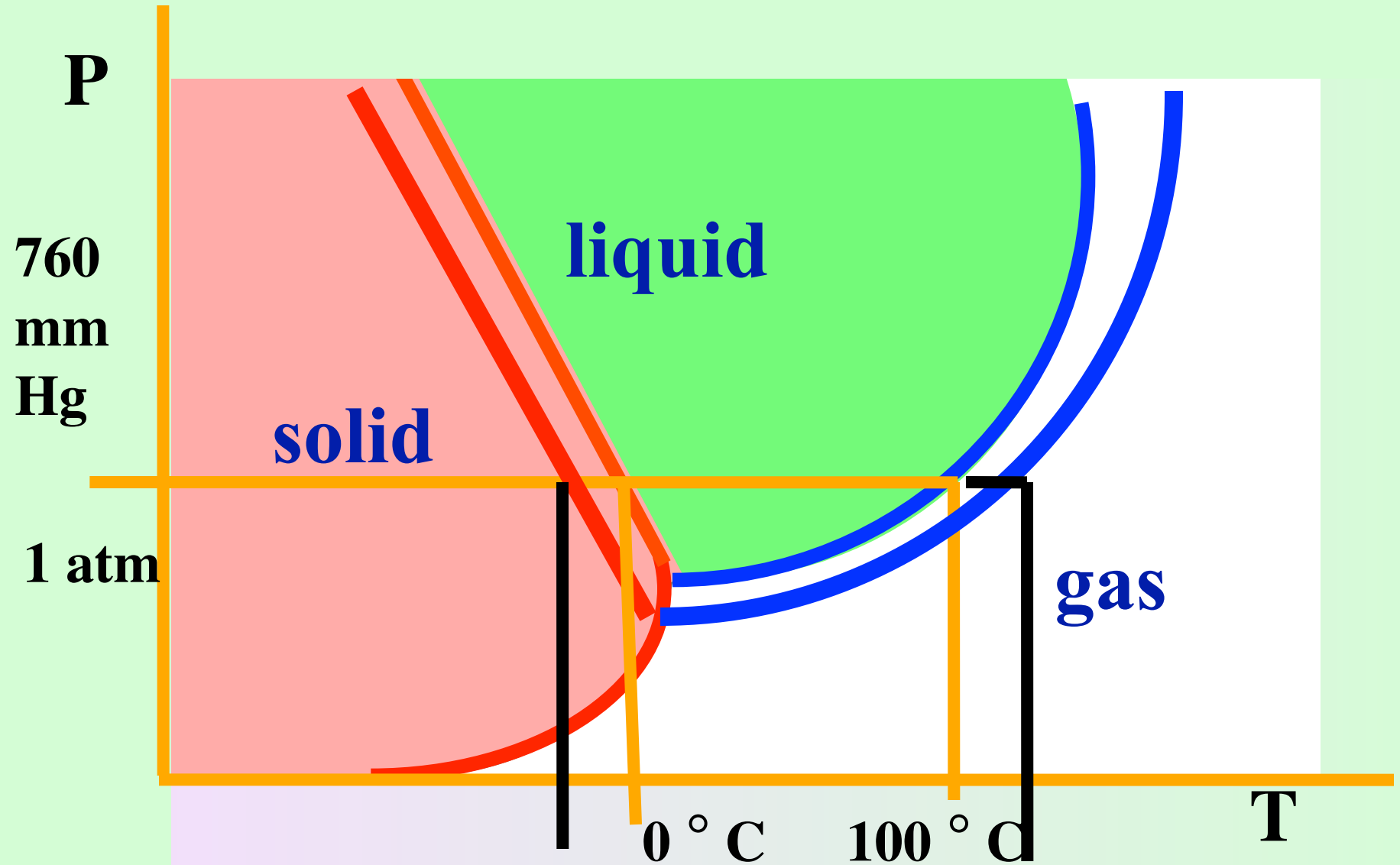
$$\frac{20\text{g urea}}{.335 \text{ mol urea}} = 59.7\text{g/mol}$$

Boiling-point elevation and freezing-point depression

Since its vapor pressure at a particular temperature is depressed, the boiling point of a substance must be **higher**.

Adding a solute to a solvent interferes with the solvent's ability to go into the solid phase. Thus **lowering** the temperature at which the solvent freezes.

Phase diagram H₂O



Boiling-point elevation

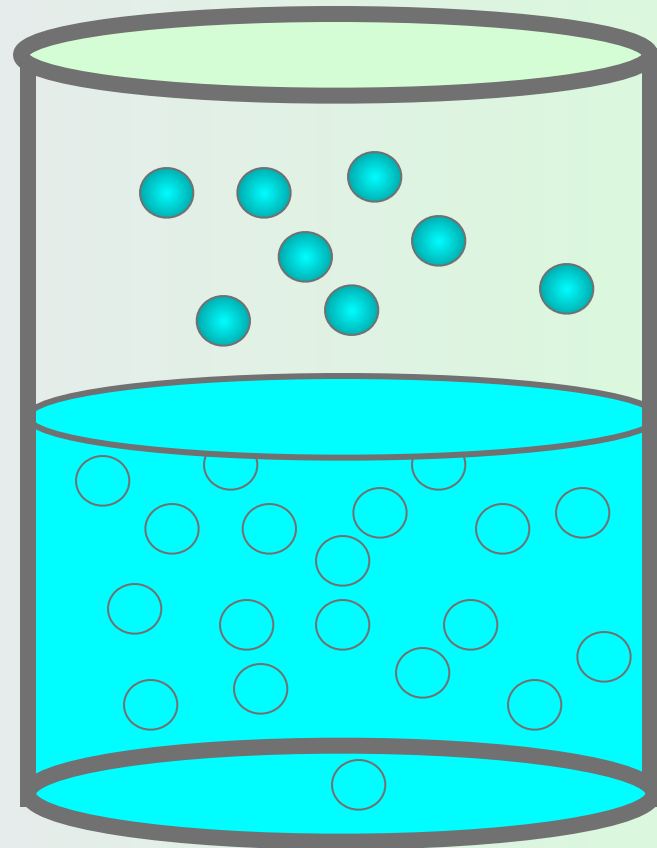
Elevation in boiling point is proportional to the molal concentration of the solute m

$$\Delta T = K_b m_{\text{solute}}$$

K_b is called the *molal boiling-point elevation constant*

Boiling point

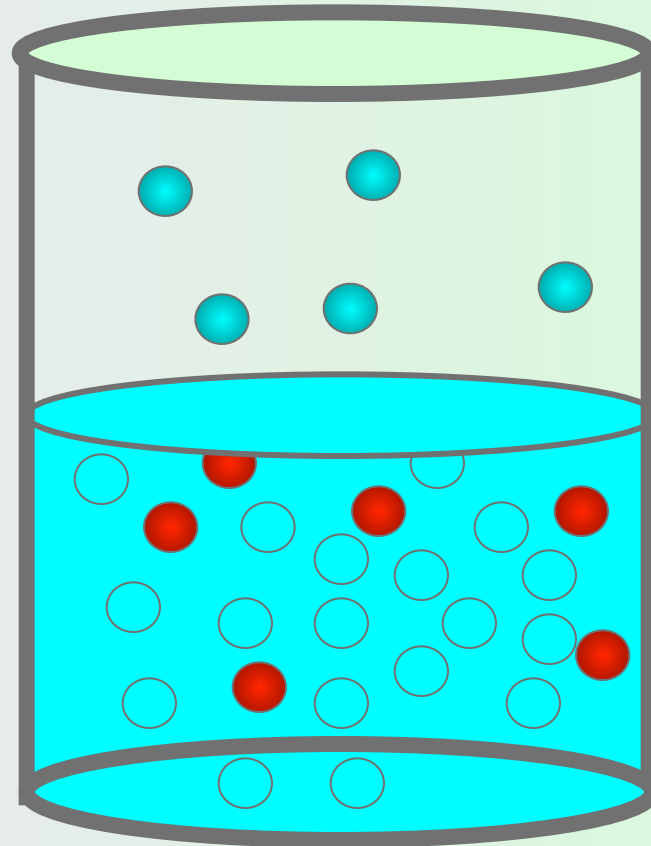
when the vapor pressure of a liquid is equal to the surrounding atmospheric pressure



Boiling point Elevation

As a nonvolatile solute is added the vapor pressure of the solvent is lowered

i.e. solvent molecules need more kinetic energy to escape into the gas phase



Freezing-point depression

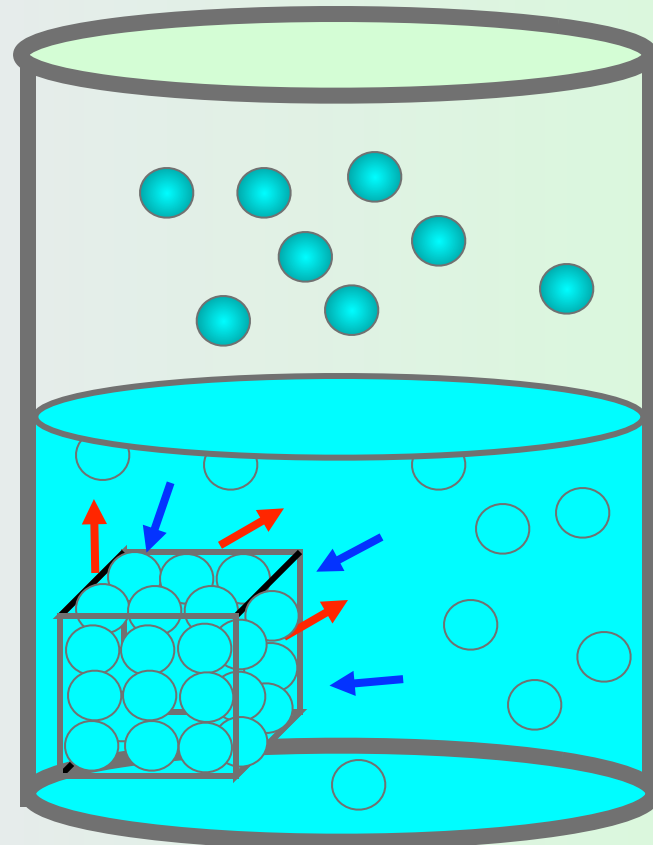
Depression in freezing is proportional to the molal concentration of the solute m

$$\Delta T = K_f m_{\text{solute}}$$

K_f is called the *molal freezing -point depression constant*

Freezing-point

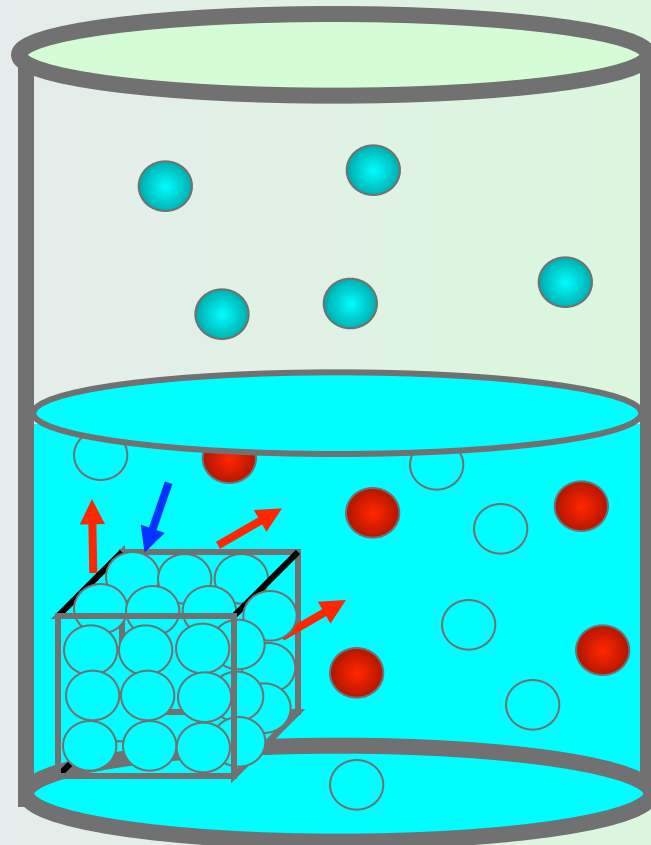
an equilibrium is established between the solid phase and the liquid phase



Freezing-point depression

the presence of a solute lowers the rate at which molecules return to the solid state

a new equilibrium is established between the solid phase and the liquid phase at a lower temperature



Boiling-point elevation

Calculate the boiling point of a solution of 0.0150 mol anthracene (which is nonvolatile) in 45.0 g of toluene (K_b for toluene is $3.33^\circ\text{C kg / mol}$); the normal boiling point of toluene is 110.63°C .

$$m = \frac{\text{Mol sol}}{\text{Kg solv}} = \frac{0.0150 \text{ mol anth.}}{45.0 \text{ g tolu.}} \times \frac{10^3 \text{ g}}{1 \text{ kg}} = \frac{0.333 \text{ mol}}{\text{kg}}$$

$$\Delta T = K_b m_{\text{solute}}$$

$$\Delta T = \frac{3.33^\circ\text{C kg}}{\text{mol}} \times \frac{0.333 \text{ mol}}{\text{kg}} = 1.11^\circ$$

$$110.63^\circ\text{C} + 1.11^\circ = 111.74^\circ\text{C}$$

Freezing point depression

Calculate the freezing point of a solution of 0.047 mol lactose (a sugar) in 25.0 g of water(K_f for water is $1.86^\circ\text{C kg} / \text{mol}$).

$$m = \frac{\text{Mol sol}}{\text{Kg solv}} = \frac{0.047 \text{ mol lac.}}{25.0 \text{ g H}_2\text{O}} \times \frac{10^3 \text{ g}}{1 \text{ kg}} = \frac{1.88 \text{ mol}}{\text{kg}}$$

$$\Delta T = K_f m_{\text{solute}}$$

$$\Delta T = \frac{1.86^\circ\text{C kg}}{\text{mol}} \times \frac{1.88 \text{ mol}}{\text{kg}} = 3.50^\circ$$

$$0^\circ\text{C} - 3.50^\circ = -3.50^\circ\text{C}$$

TABLE 13.3 • Molal Boiling-Point-Elevation and Freezing-Point-Depression Constants

Solvent	Normal Boiling Point (°C)	K_b (°C/<i>m</i>)	Normal Freezing Point (°C)	K_f (°C/<i>m</i>)
Water, H ₂ O	100.0	0.51	0.0	1.86
Benzene, C ₆ H ₆	80.1	2.53	5.5	5.12
Ethanol, C ₂ H ₅ OH	78.4	1.22	-114.6	1.99
Carbon tetrachloride, CCl ₄	76.8	5.02	-22.3	29.8
Chloroform, CHCl ₃	61.2	3.63	-63.5	4.68

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Osmotic Pressure (π)

Semipermeable membrane:

allows solvent molecules to pass through but not solute molecules

osmosis:

The passing of solvent molecules across a semipermeable membrane

Osmotic Pressure (π)

the pressure required to stop osmosis

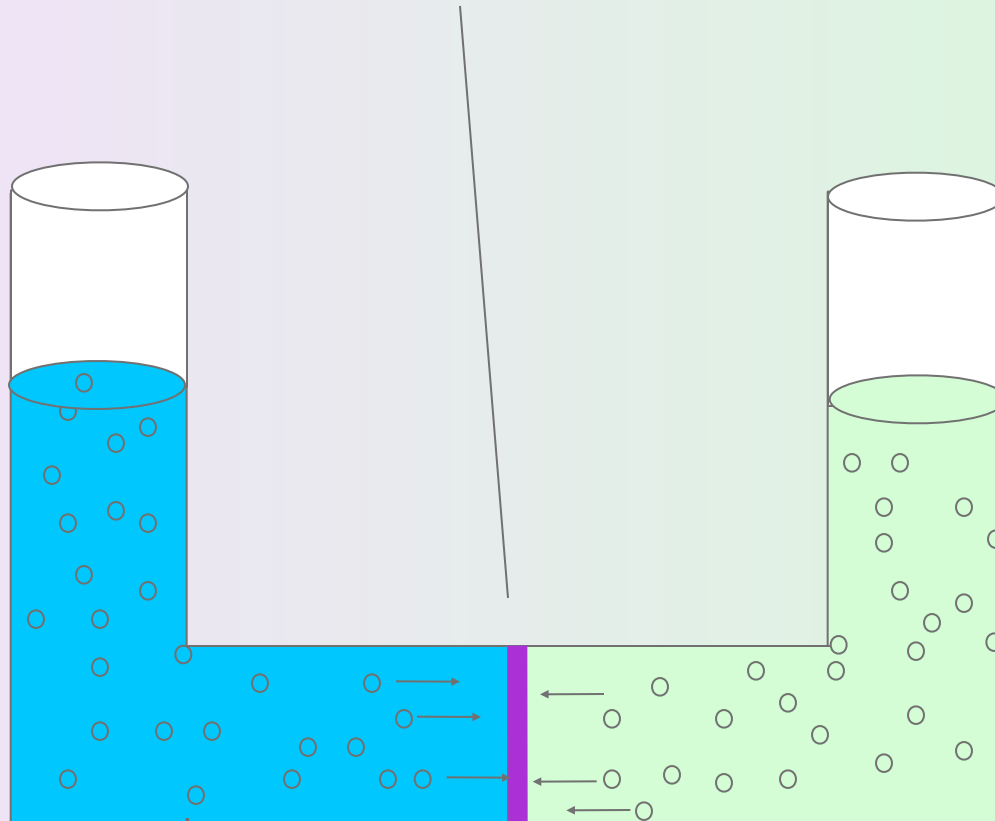
$$\pi = MRT$$

(M) molarity of the solute

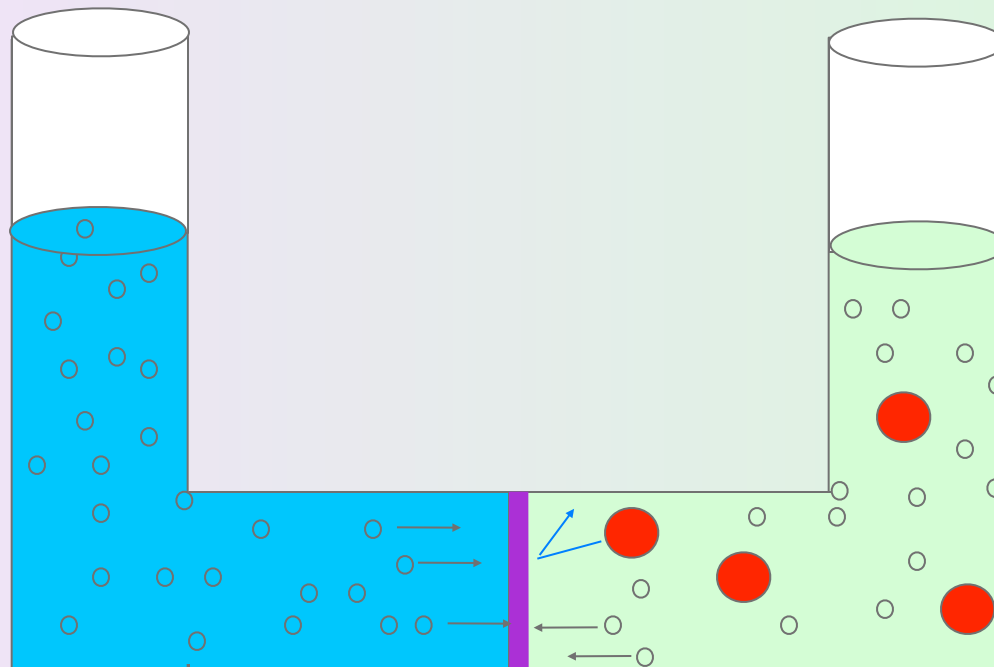
(R) gas law constant

(T) kelvin temperature

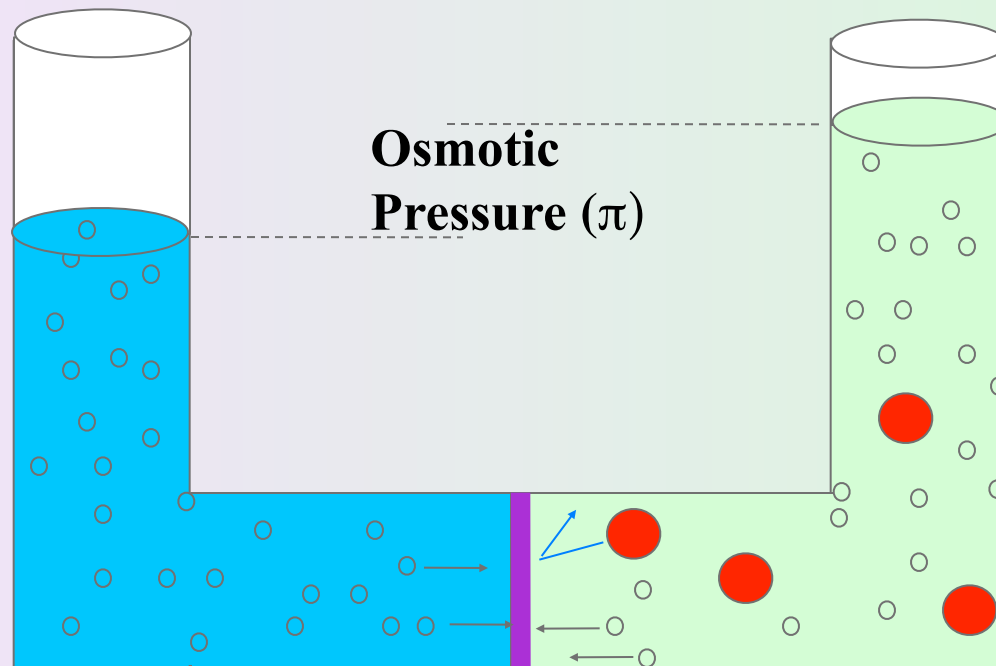
Porous Barrier



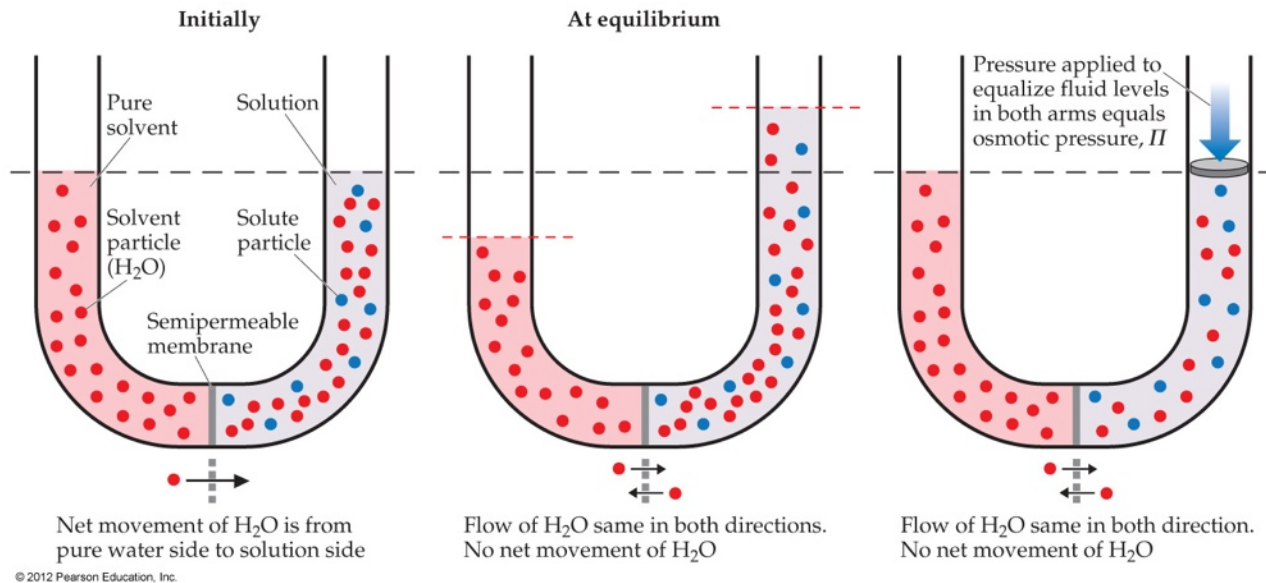
the rate of transfer is greater from solvent to solution than from solution to solvent



at equilibrium the rate of solvent transfer is the same in both directions



Osmosis



In osmosis, there is net movement of solvent from the area of **higher solvent concentration** (*lower solute concentration*) to the area of **lower solvent concentration** (*higher solute concentration*).



Osmotic Pressure (π)

1.0×10^{-3} g of protein is dissolved in 1.0 ml of water. The osmotic pressure of this solution was found to be 1.12 torr at 25.0°C . Calculate the molar mass of the protein (density of the solution is 1 g/L)

$$M = \pi / RT$$

$$\pi = 1.12 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 1.47 \times 10^{-3} \text{ atm}$$

$$M = \frac{1.47 \times 10^{-3} \text{ atm}}{(0.0821 \text{ L atm/ K mol})(298\text{K})} = 6.01 \times 10^{-5} \text{ mol/L}$$

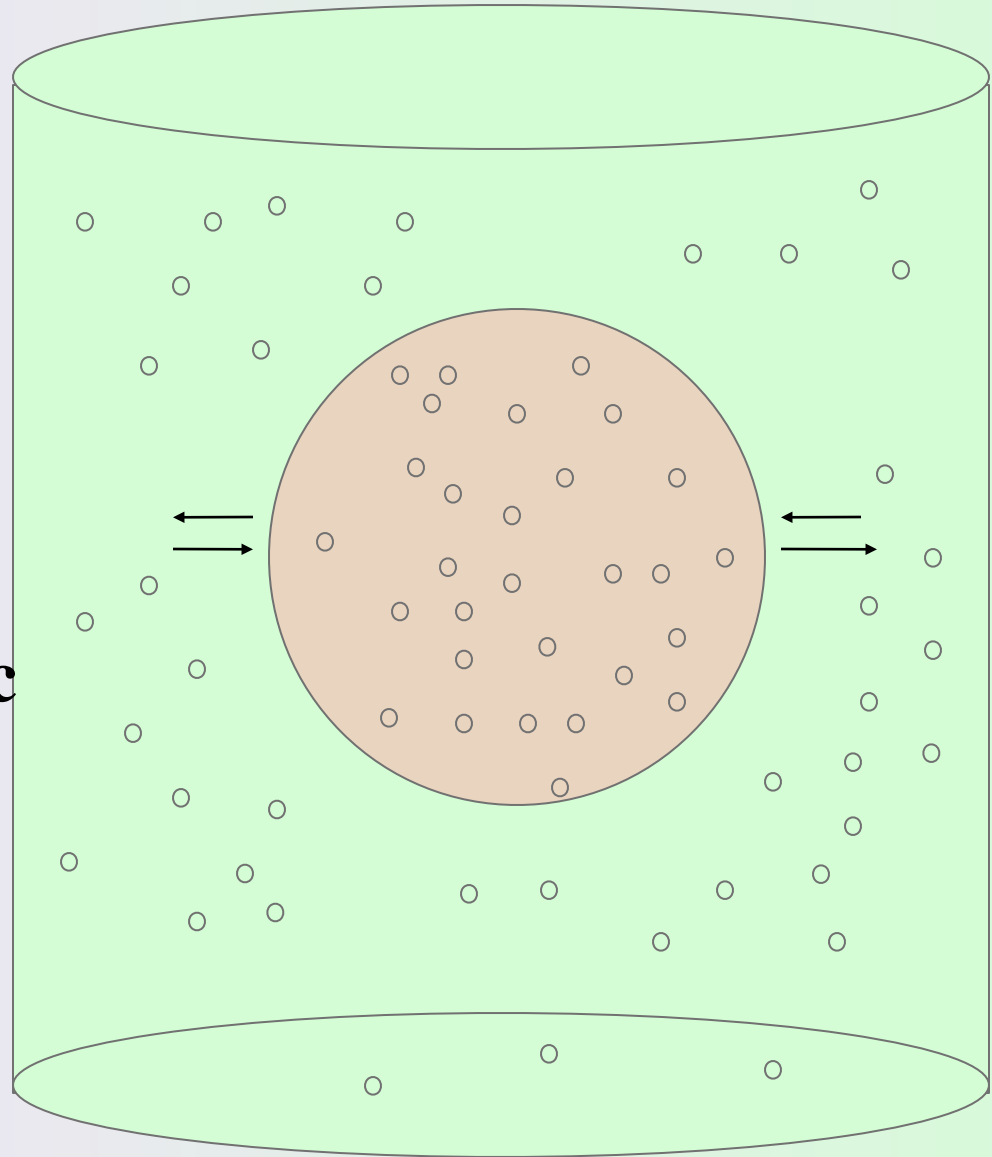
$$d = \frac{1 \text{ g}}{\cancel{\text{L}}} \times \frac{\cancel{1\text{L}}}{6.01 \times 10^{-5} \text{ mol}} = \frac{1 \text{ g}}{6.01 \times 10^{-5} \text{ mol}}$$

$$\frac{1 \text{ g}}{6.01 \times 10^{-5} \text{ mol}} = 1.66 \times 10^4 \text{ g/mol}$$

Dialysis

Isotonic solutions

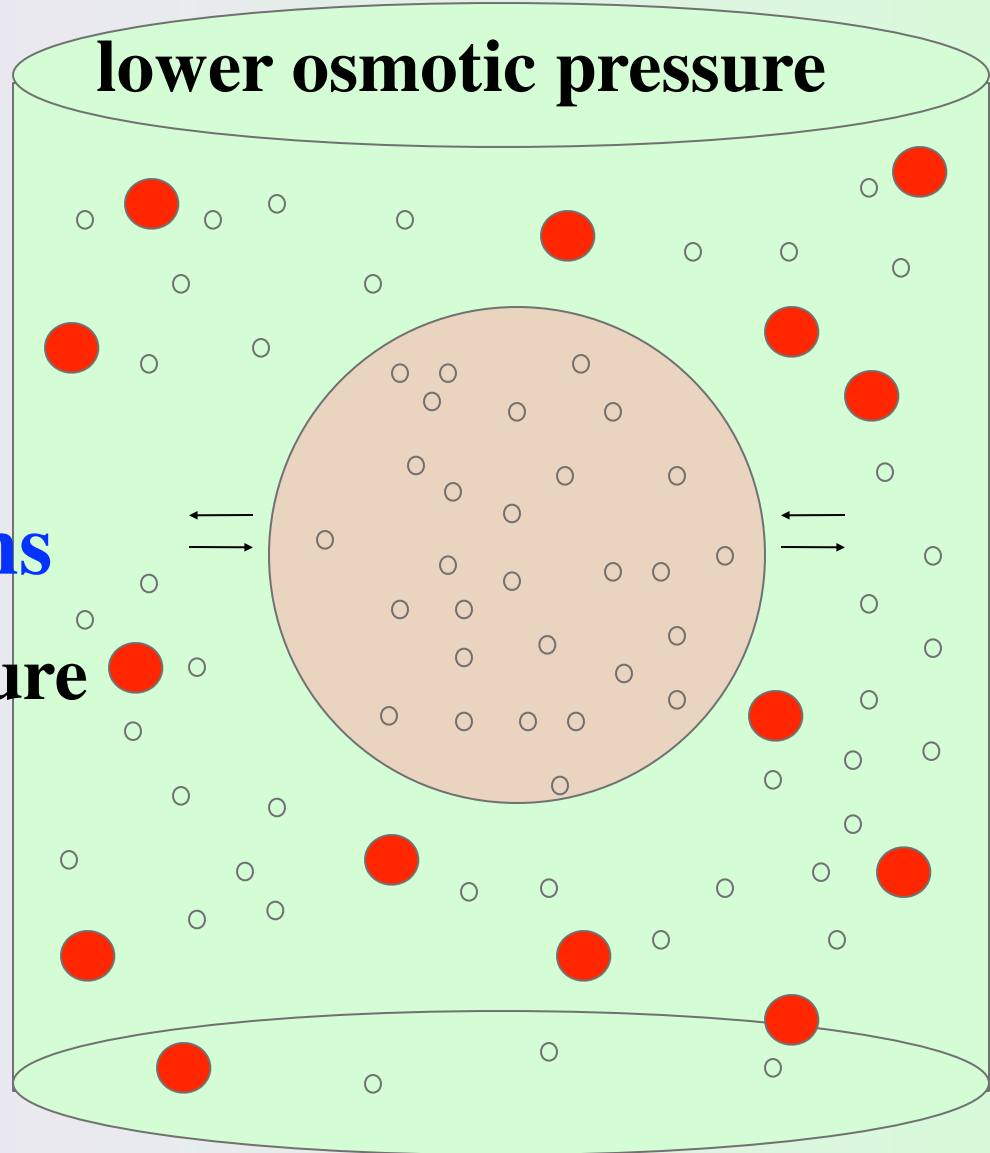
have identical osmotic pressures



Dialysis

Hypotonic solutions

lower osmotic pressure



Hypertonic solutions

Higher osmotic pressure

Dialysis

**A new
equilibrium
established**

