Solutions

A solution is a   of two or more substances in **one** phase

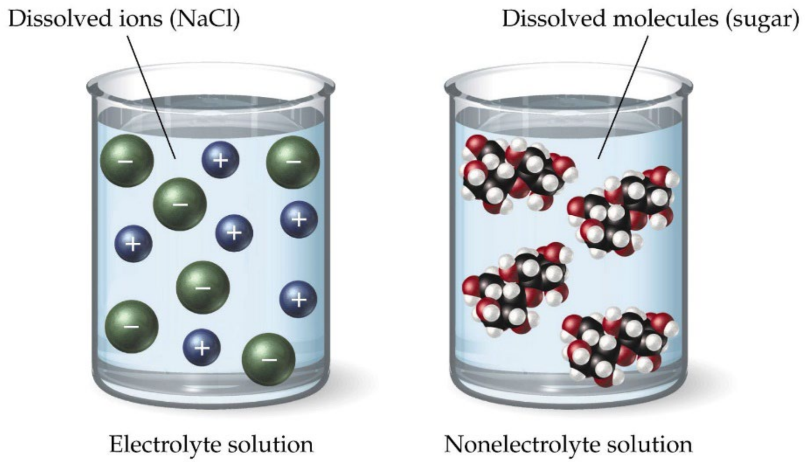
Solute   :   abundant
Solvent :   abundant   ➡   The   is dissolved in the

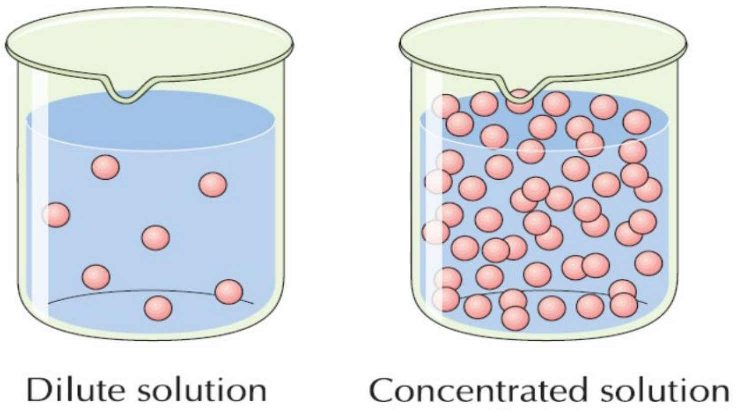
Not Solutions

Cement
Mud water   ➡   Heterogeneous solution

Solutions	Solvent	Solute	Phase
Salt water	H_2O		Liquid
Sugar water	H_2O	$CH_{12}H_{22}O_{11}$	
Air		O_2	Gas
Brass	Cu	Zn	Solid
Ruby	Al_2O_3		

Aqueous Solutions: Water solvent





How much solute is dissolved ?

More quantitative description

* Temperature dependent*

Molarity (*M*)

M =

EX. Find the molarity if 5.22 g NaCl is dissolved in enough water to form 125 ml solution

Normality (*N*) =

Acid-base
Oxidation-reduction

EX. Find the normality of 3.75 *M* $H_2SO_{4(aq)}$

EX. Find the equivalent mass of 1 *M* $MnO_4^-{}_{(aq)}$

$$MnO_4^- + 5\,e^- + 8\,H^+ \rightarrow Mn^{2+} + H_2O$$

Mass percent

Mole fraction (χ_A)

χ_A =

EX. Find the mole fraction of KBr if 7.31 g KBr is mixed with 50.0 g water

Molality (m)

m =

EX. Find the molality of 10.5 g KBr is dissolved in 212 g of water

Converting Concentrations

Molarity (M) to Molality (m)

EX. 3 M HCl, D_{HCl} = 1.050 g/ml at 25°C

Assuming 1L solution

Molality (m) to Mole fraction (χ_A)

Assuming 1.000 kg solvent

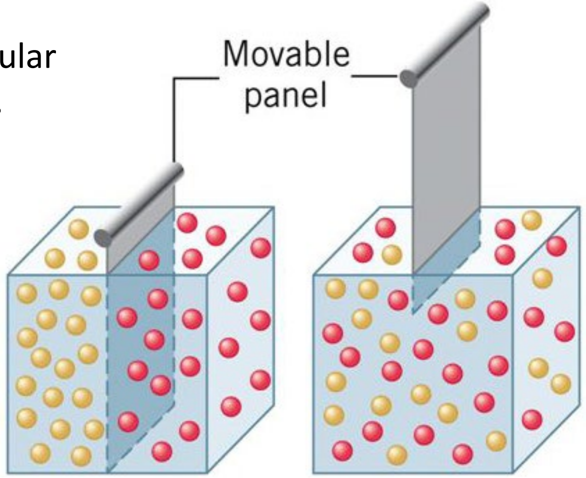
Mole fraction (χ_A) to Molarity (M)

Assuming 1.000 mole (Total)

Solution Formation

Q1: What happens when a solution forms?

Note: no intermolecular interaction involved.



Before (low entropy)

A measure of disorder

After (high entropy)

Q2: Why do the mix?

The random particle motion leads to a mixed configuration of particles which is the

Other examples:

- ☐ Opening a perfume bottle
- ☐ Spilling a bucket of marbles
- ☐ Boys and girls at their first school dance

Mixing is

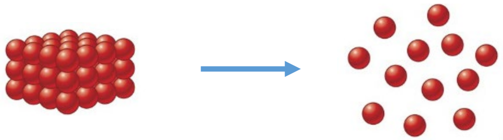
if no other forces are involved

Energetics of Solution Formation

Breaking interaction **cost** energy (+)

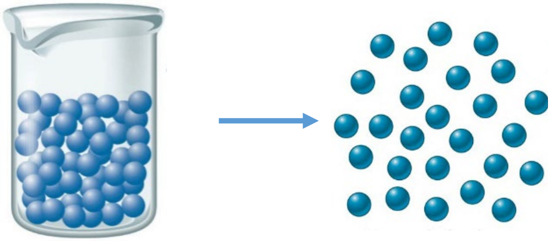
Forming interaction **release** energy (−)

1. Separate solute particles (+)



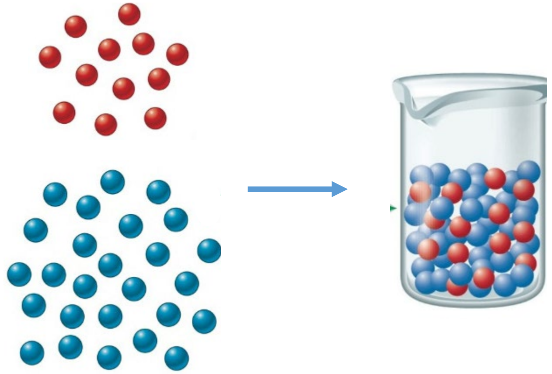
ΔH_{solute} **0**,
Large and for ionic solute (lattice energy)

2. Separate solvent particles (+)



$\Delta H_{solvent}$ **0**,

3. combine Solute and Solvent (−)



ΔH_{mix} **0**,
Large and for ionic solute (ion-dipole int.)

$\Delta H_{solution}$ = + +

Solution Formation

Solution process			$\Delta H_{solution}$ (kJ/mol)	
KOH	$\xrightarrow{H_2O}$	$K^+_{(aq)} + OH^-_{(aq)}$	-57.61	Heat released, Temperature ↑
$AgNO_3$	$\xrightarrow{H_2O}$	$Ag^+_{(aq)} + NO^-_{3(aq)}$	36.91	Heat absorbed, Temperature ↓
$C_{12}H_{22}O_{11}$	$\xrightarrow{H_2O}$	$C_{12}H_{22}O_{11(aq)}$	6.09	Heat absorbed, Temperature ↓

Q1: What makes $\Delta H_{solution} > 0$?

➡ Strong and interactions which outweigh the weak interactions

Q2: If the interactions are so strong, what causes them to break so the solution can form?

➡ from the surrounding provides the energy needed to break the interactions. is always a preferred process.

Solubility

Solubility is the   of solute that dissolves in a given amount of solvent.

Thought experiment : add too much salt to water

$NaCl_{(s)} \rightarrow NaCl_{(aq)}$

$NaCl_{(s)}$ $NaCl_{(aq)}$
un-saturated

$NaCl_{(s)} \rightleftarrows NaCl_{(aq)}$
Saturated
Dynamic equilibrium

A **super-saturated** solution has more than the max amount of solute dissolved.

Q: How is a supersaturated solution made?

EX. The solubility of sucrose in water $\chi(25°C) = 0.1$, and $\chi(100°C) = 0.2$.
Boil together 9.0 mole H_2O and 2.0 mole sucrose

$\chi = 2/(9+2)$
$= 0.18 < 0.2$
Unsaturated

Carefully cooling →

$\chi = 0.18 > 0.1$
Super-saturated

Disturb →

$\chi = 0.1 > 0.1$
saturated

Factors affecting solubility

Like-dissolve-Like

Liquid-Liquid

Hydrophilic vs hydrophobic

Ex: H_2O and CH_3CH_2OH (yes)

Ex: H_2O and $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$ ( )

Ex: H_2O and $CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$ ( )

Solid-Liquid

- polar solid usually dissolve in water
- nonpolar solid usually do not dissolve in water

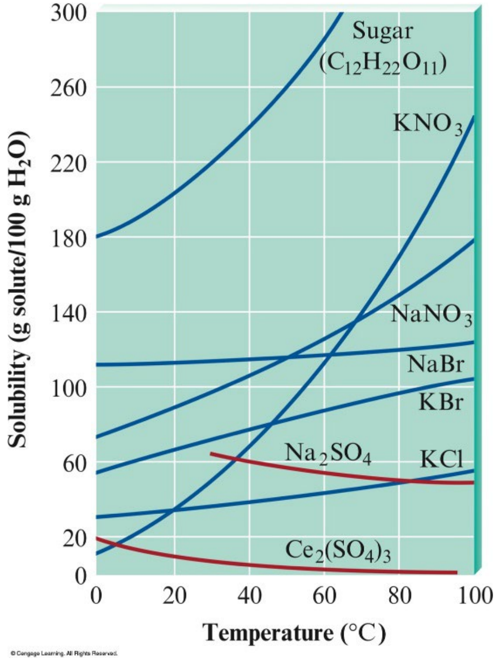
Ex: $C_6H_{12}O_6$

Ex: I_2

Factors affecting solubility

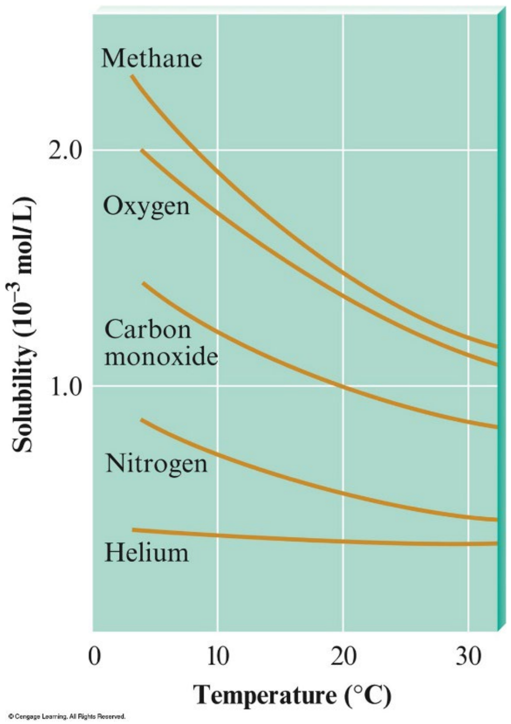
Temperature

The solubility of most **solids** (in water) with temperature.



Solid	ΔH_{soln} (KJ/mol)
$NaNO_3$	20.5
NaBr	-0.60
KBr	19.87
Na_2SO_4	2.2
NaCl	3.88

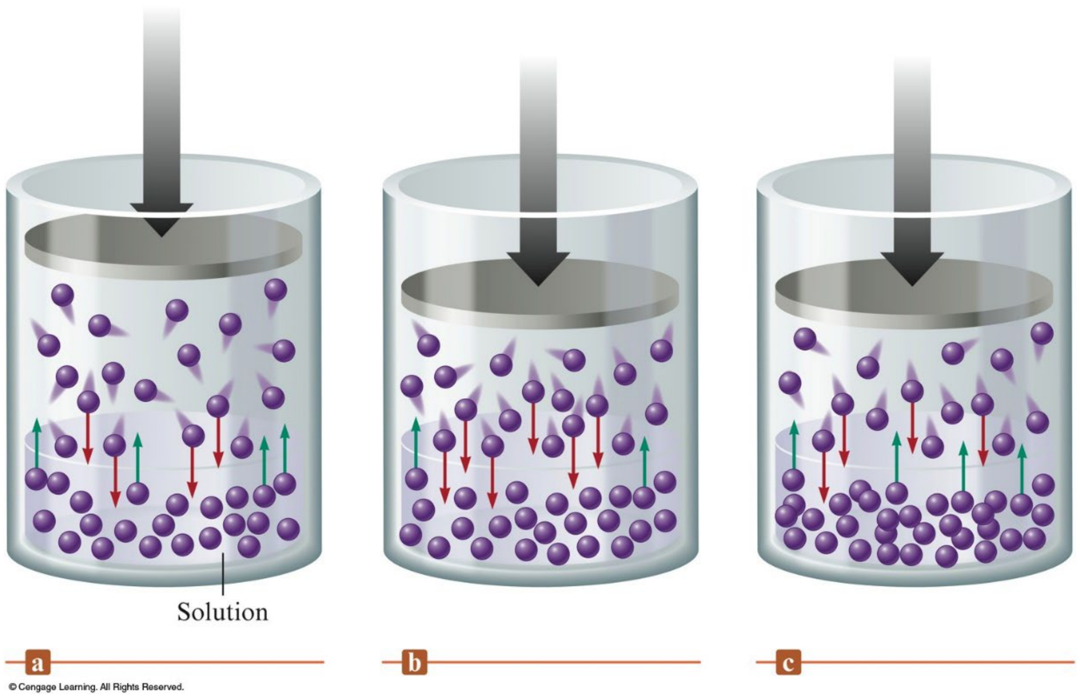
The solubility of most **gases** (in water) with temperature.



Factors affecting solubility

Pressure

The solubility of a gas in a liquid
as its partial pressure above increase.



$CO_{2(g)} \rightleftarrows CO_{2(aq)}$ equilibrium

$CO_{2(g)}$ $CO_{2(aq)}$

$CO_{2(g)} \rightleftarrows CO_{2(aq)}$ equilibrium

Henry's Law: $C_g = k_H P_g$

C_g = concentration of dissolved gas
k_H = constant
P_g =partial pressure of gas solute above the solution

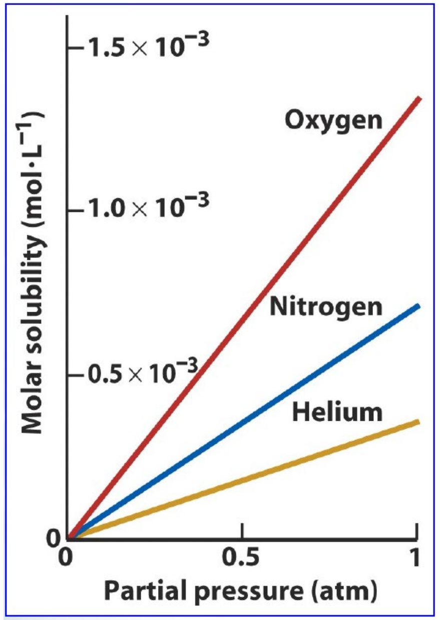


TABLE 8.5 Henry's Constants for Gases in Water at 20.°C

Gas	k_H ($mol \cdot L^{-1} \cdot atm^{-1}$)
air	7.9×10^{-4}
argon	1.5×10^{-3}
carbon dioxide	2.3×10^{-2}
helium	3.7×10^{-4}
hydrogen	8.5×10^{-4}
neon	5.0×10^{-4}
nitrogen	7.0×10^{-4}
oxygen	1.3×10^{-3}

EX. What pressure of CO_2 is required to keep concentration of CO_2 in a bottle of root beer at 0.13 *M*?

Colligative Properties

Properties of solutions that depend on the
of dissolved particles and **not the type**

Properties of are different than
properties of **solvents**.

Why ??

particles get in the way !!!

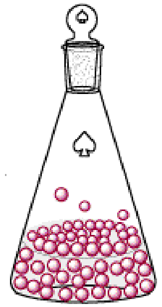
1. Vapor Pressure Lowering

Thought experiment : Pour water in a flask and cork it.

$H_2O_{(l)} \rightarrow H_2O_{(g)}$

$H_2O_{(l)} \rightarrow H_2O_{(g)}$
$R_{vap} > R_{condensation}$

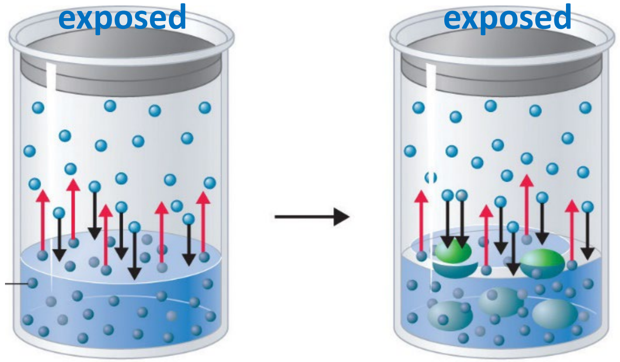
$H_2O_{(l)} \rightarrow H_2O_{(g)}$
$R_{vap} = R_{condensation}$
Dynamic Equilibrium



Note:
Evaporation occurs
at the **surface**
at any **temperature**

24 Torr
Entire surface exposed

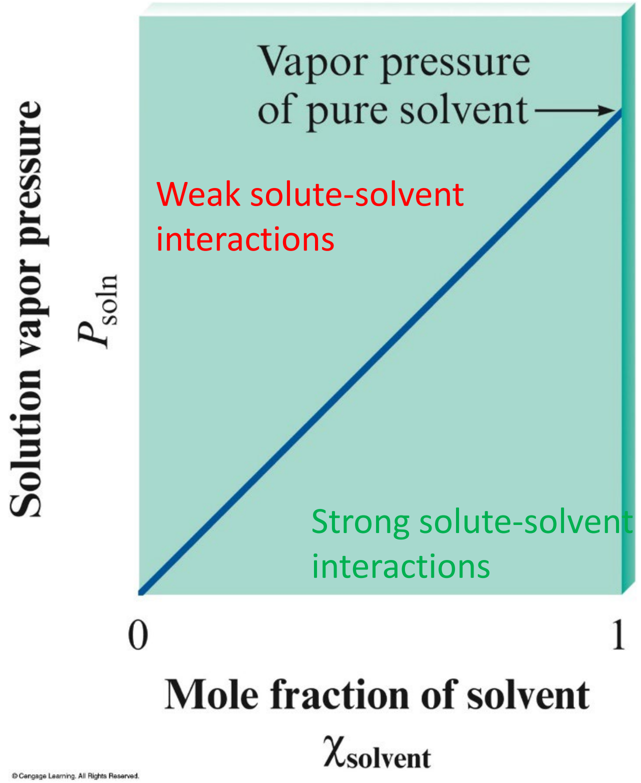
12 Torr
Only 1/2 surface exposed



Raoult's Law: $P_{soln} = \chi_{solv} P°_{solv}$

P_{soln} = vapor pressure of **solution**
χ_{solv} = mole fraction of **solvent**
$P°_{solv}$ = vapor pressure of **pure solvent**

Ex: Find the vapor pressure above a solution of 1.0 mol glucose ($C_6H_{12}O_6$) dissolved in 9.0 mol H_2O at 25℃.

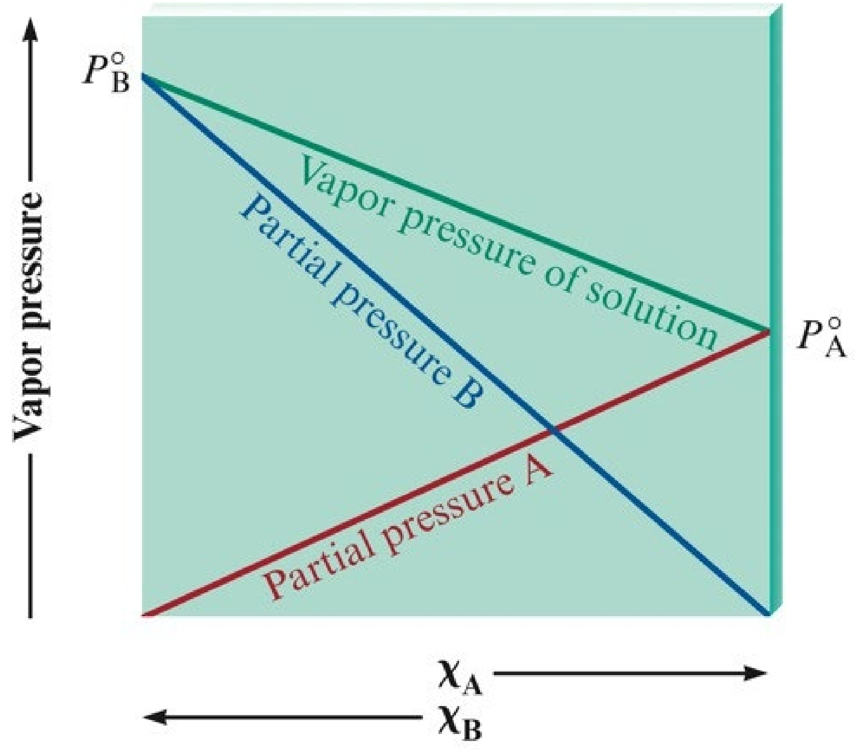


Raoult's Law: $P_{soln} = \chi_{solv} P°_{solv}$

Volatile Solute

If the solute has a significant vapor pressure, then it must also be accounted for.

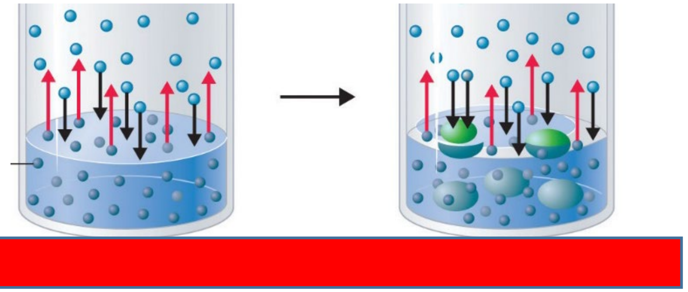
Ex: Find the total vapor pressure above a solution that contains f 1.0 mol CH_3CH_2OH and 1.0 mol H_2O at 25°C. $P°_{EtOH}$ = 44.6 Torr and $P°_{H2O}$ = 23.9 Torr



2. Boiling Point Elevation

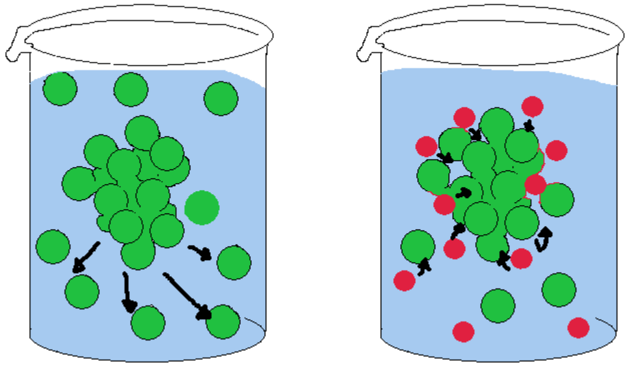
Recall:

The B.P. is the temperature at which $P_{vap} = P_{1atm}$.



$$\Delta T_b = K_b\, m_{solute}$$

3. Freezing Point Depression



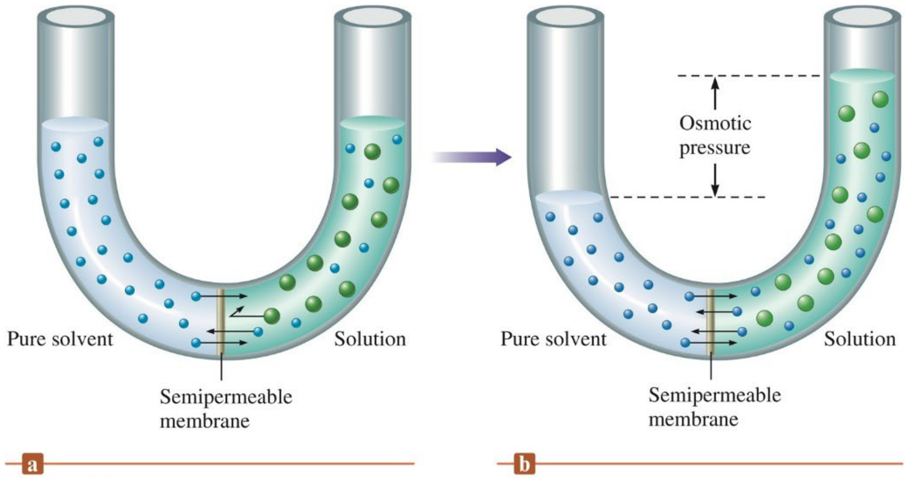
$$\Delta T_f = K_f\, m_{solute}$$

TABLE 13.4 Molal Boiling-Point-Elevation and Freezing-Point-Depression Constants

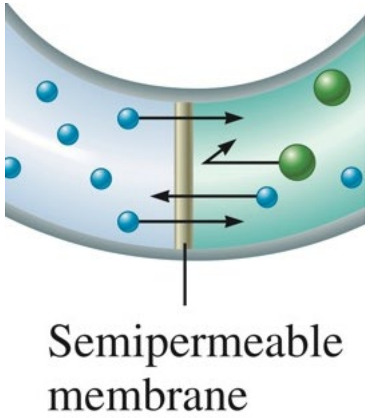
Solvent	Normal Boiling Point (°C)	K_b (°C/*m*)	Normal Freezing Point (°C)	K_f (°C/*m*)
Water, H_2O	100.0	0.52	0.0	1.86
Benzene, C_6H_6	80.1	2.53	5.5	5.12
Ethanol, C_2H_5OH	78.4	1.22	–114.6	1.99
Carbon tetrachloride, CCl_4	76.8	5.02	–22.3	29.8
Chloroform, $CHCl_3$	61.2	3.63	–63.5	4.68

4. Osmotic Pressure

Initial **equilibrium**



Solute particles move around and exert pressure just like gas molecule



This extra weight is held up by the **osmotic pressure** of the solution

$$\Pi = MRT$$

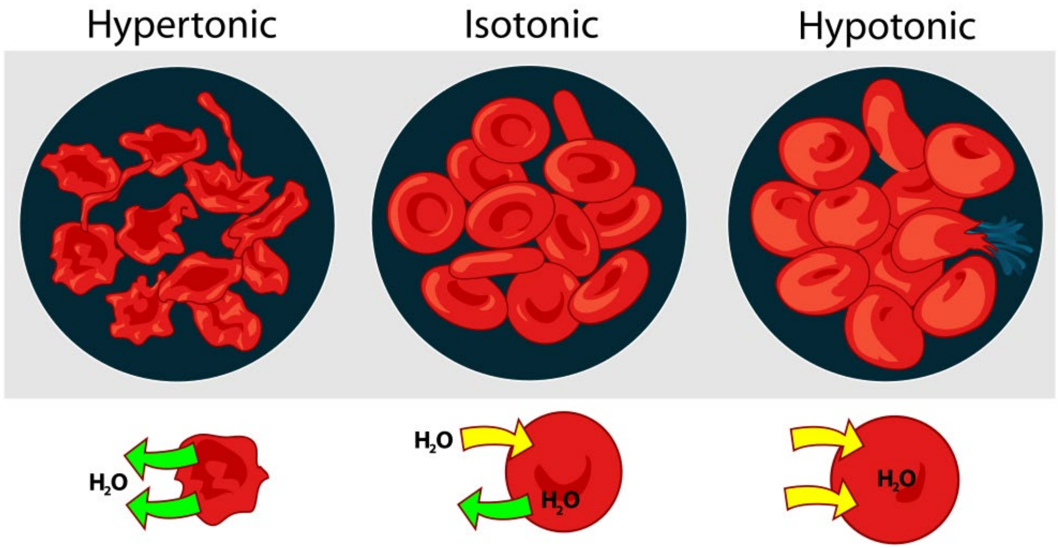
Π : osmotic pressure
M : Molarity
R : Gas constant
T : Temperature

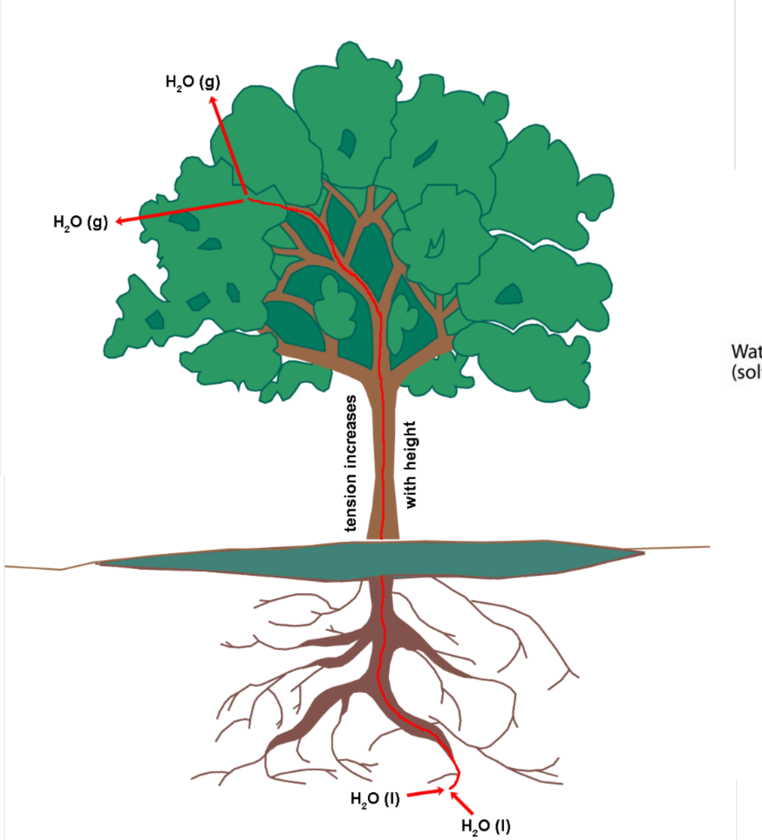
Recall:
Ideal Gas Law: $PV = nRT$, $P = (n/V)RT = MRT$

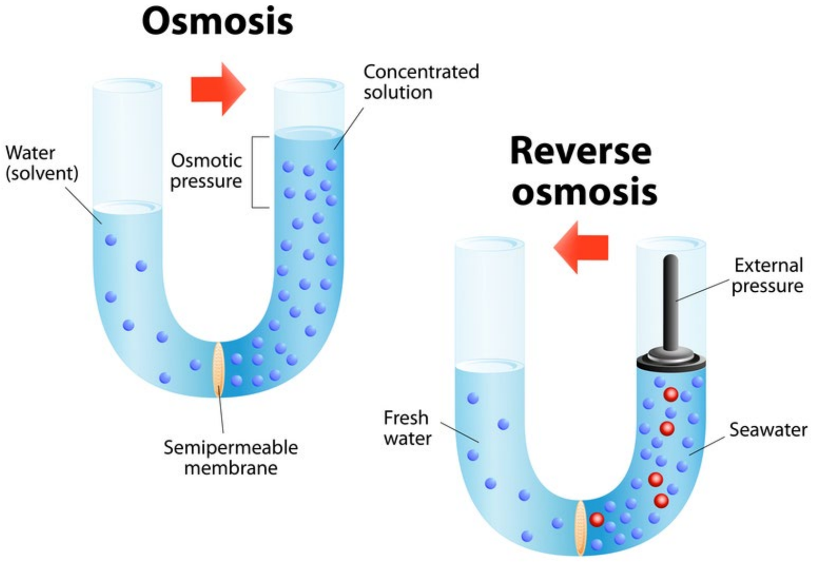
Ex: A solution containing 35.0 g hemoglobin dissolved in water to from 1.00 L solution exerts an osmatic pressure of 10.0 Torr at 25℃. Find the molar mass of hemoglobin.

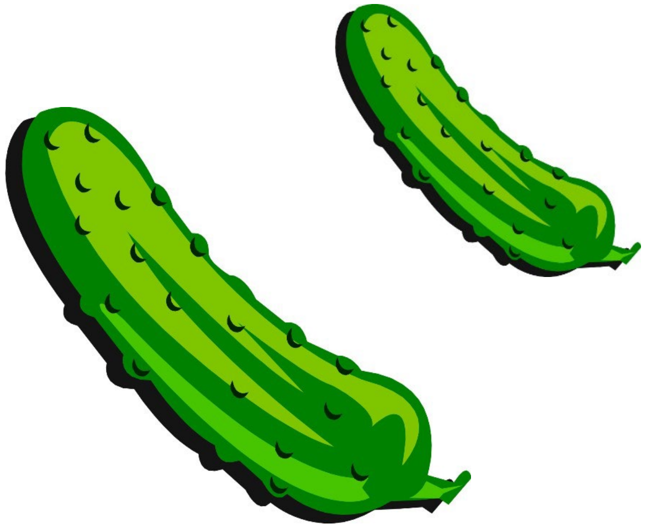
4. Osmotic Pressure applications

1. Medical solutions
2. Water movement up tree trunk
3. Water purification
4. Making a pickle

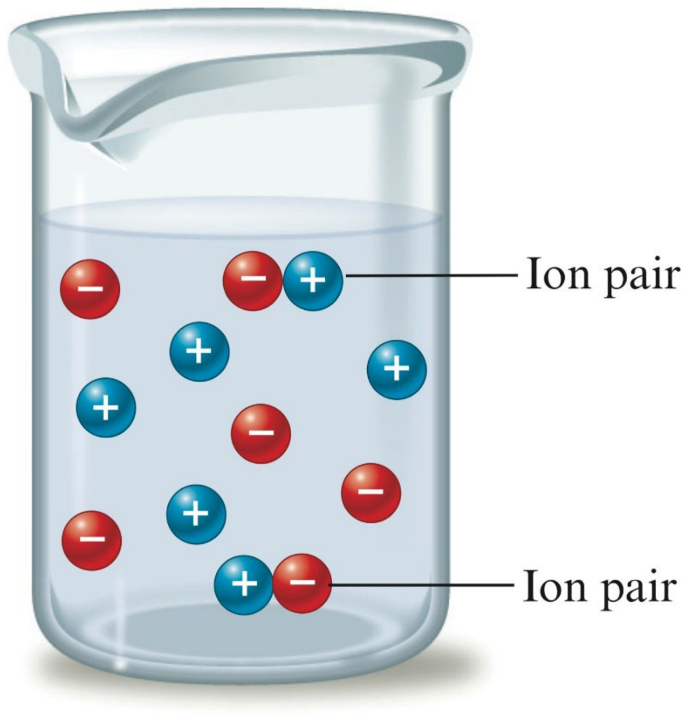








van't Hoff factor, *i*



Expected and Observed Values of the van't Hoff Factor for 0.05 *m* Solutions of Several Electrolytes

Electrolyte	*i* (expected)	*i* (observed)
NaCl	2.0	1.9
$MgCl_2$	3.0	2.7
$MgSO_4$	2.0	1.3
$FeCl_3$	4.0	3.4
HCl	2.0	1.9
Glucose*	1.0	1.0

*A nonelectrolyte shown for comparison.

$\Delta T_b = iK_b m_{solute}$

$\Delta T_f = iK_f m_{solute}$

$\Pi = iMRT$

Ex: Find the B.P of 0.9 *m* $FeCl_{3(aq)}$

Colloids

- A suspension of tiny particles in some medium.
- Tyndall effect – scattering of light by particles.
- Suspended particles are single large molecules or aggregates of molecules or ions ranging in size from 1 to 1000 nm.

Table 11.7 | Types of Colloids

Examples	Dispersing Medium	Dispersed Substance	Colloid Type
Fog, aerosol sprays	Gas	Liquid	Aerosol
Smoke, airborne bacteria	Gas	Solid	Aerosol
Whipped cream, soap suds	Liquid	Gas	Foam
Milk, mayonnaise	Liquid	Liquid	Emulsion
Paint, clays, gelatin	Liquid	Solid	Sol
Marshmallow, polystyrene foam	Solid	Gas	Solid foam
Butter, cheese	Solid	Liquid	Solid emulsion
Ruby glass	Solid	Solid	Solid sol