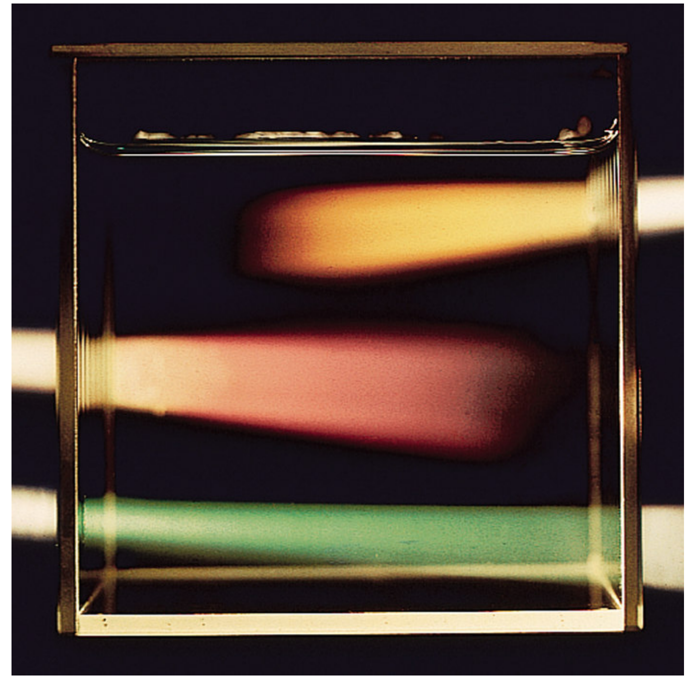


Physical Properties of Solutions

Chapter 12

A ***solution*** is a homogenous mixture of 2 or more substances

The ***solute*** is(are) the substance(s) present in the smaller amount(s)

The ***solvent*** is the substance present in the larger amount

TABLE 12.1 Types of Solutions

Component 1	Component 2	State of Resulting Solution	Examples
Gas	Gas	Gas	Air
Gas	Liquid	Liquid	Soda water (CO_2 in water)
Gas	Solid	Solid	H_2 gas in palladium
Liquid	Liquid	Liquid	Ethanol in water
Solid	Liquid	Liquid	NaCl in water
Solid	Solid	Solid	Brass (Cu/Zn), solder (Sn/Pb)

A ***saturated solution*** contains the maximum amount of a solute that will dissolve in a given solvent at a specific temperature.

An ***unsaturated solution*** contains less solute than the solvent has the capacity to dissolve at a specific temperature.

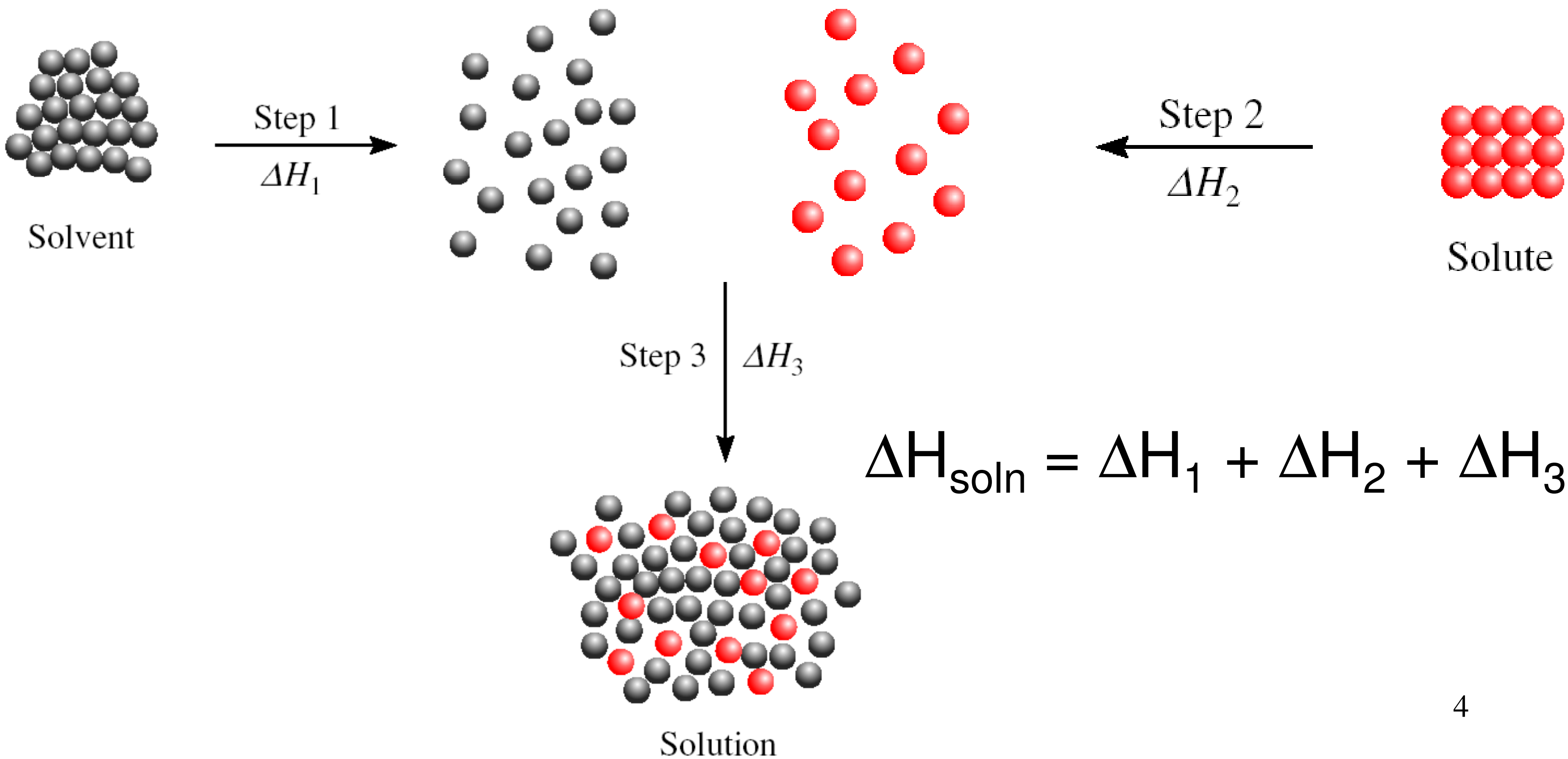
A ***supersaturated solution*** contains more solute than is present in a saturated solution at a specific temperature.

Sodium acetate crystals rapidly form when a seed crystal is added to a supersaturated solution of sodium acetate.

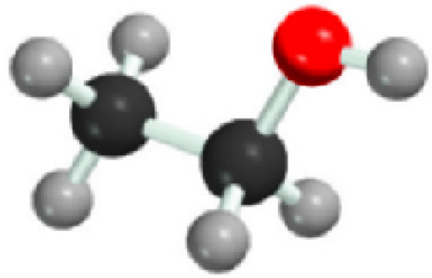
Three types of interactions in the solution process:

- solvent-solvent interaction
- solute-solute interaction
- solvent-solute interaction

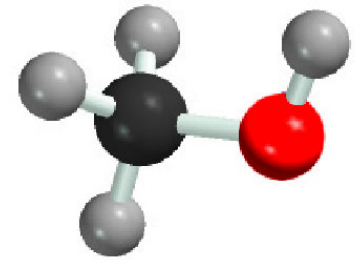
Molecular view of the formation of solution



$$\Delta H_{soln} = \Delta H_1 + \Delta H_2 + \Delta H_3$$



"**like dissolves like**"



Two substances with similar ***intermolecular*** forces are likely to be soluble in each other.

- non-polar molecules are soluble in non-polar solvents

  CCl_4 in C_6H_6

- polar molecules are soluble in polar solvents

  C_2H_5OH in H_2O

- ionic compounds are more soluble in polar solvents

  NaCl in H_2O or NH_3 (*l*)

Concentration Units

The ***concentration*** of a solution is the amount of solute present in a given quantity of solvent or solution.

Percent by Mass

$$\% \text{ by mass} = \frac{\text{mass of solute}}{\text{mass of solute + mass of solvent}} \times 100\%$$

$$= \frac{\text{mass of solute}}{\text{mass of solution}} \times 100\%$$

Mole Fraction ***(X)***

$$X_A = \frac{\text{moles of A}}{\text{sum of moles of all components}}$$

Concentration Units Continued

Molarity ***(M)***

$$M = \frac{\text{moles of solute}}{\text{liters of solution}}$$

Molality ***(m)***

$$m = \frac{\text{moles of solute}}{\text{mass of solvent (kg)}}$$

What is the molality of a 5.86 *M* ethanol (C_2H_5OH) solution whose density is 0.927 g/mL?

$$m = \frac{\text{moles of solute}}{\text{mass of solvent (kg)}} \qquad M = \frac{\text{moles of solute}}{\text{liters of solution}}$$

Assume 1 L of solution:

5.86 moles ethanol = 270 g ethanol

927 g of solution (1000 mL x 0.927 g/mL)

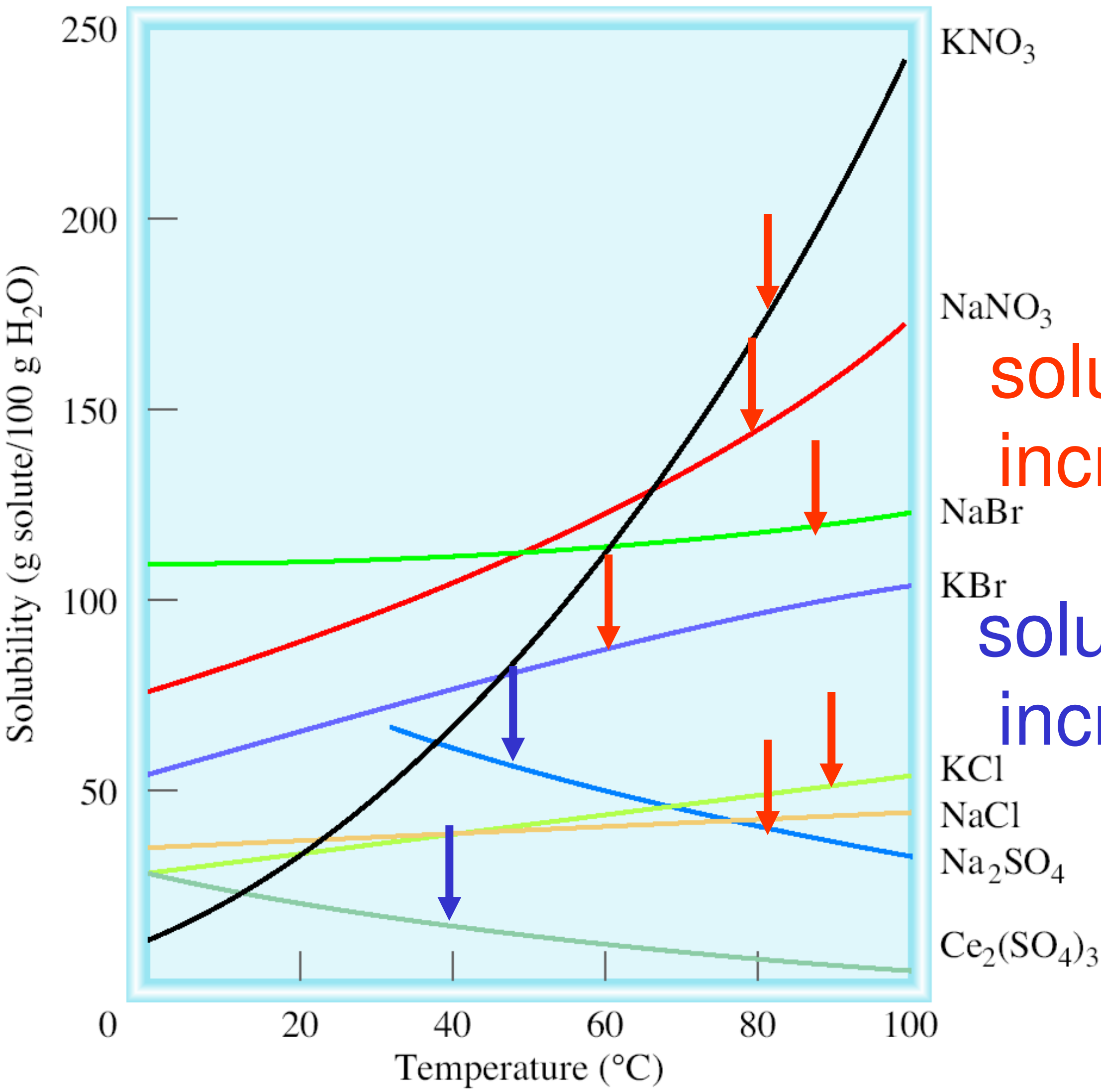
mass of solvent = mass of solution – mass of solute

= 927 g – 270 g = 657 g = 0.657 kg

$$m = \frac{\text{moles of solute}}{\text{mass of solvent (kg)}} = \frac{5.86 \text{ moles } C_2H_5OH}{0.657 \text{ kg solvent}} = 8.92\ m$$

Temperature and Solubility

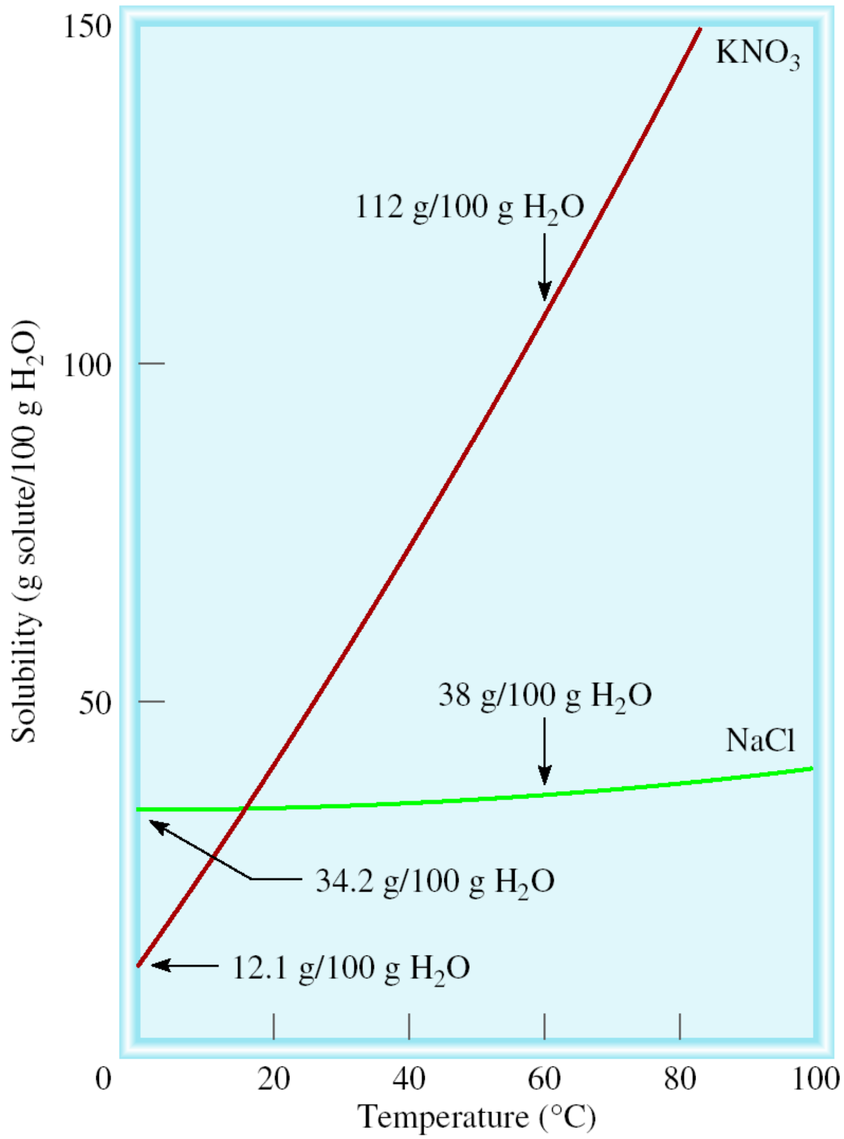
Solid solubility and temperature



solubility increases with increasing temperature

solubility decreases with increasing temperature

Fractional crystallization is the separation of a mixture of substances into pure components on the basis of their differing solubilities.



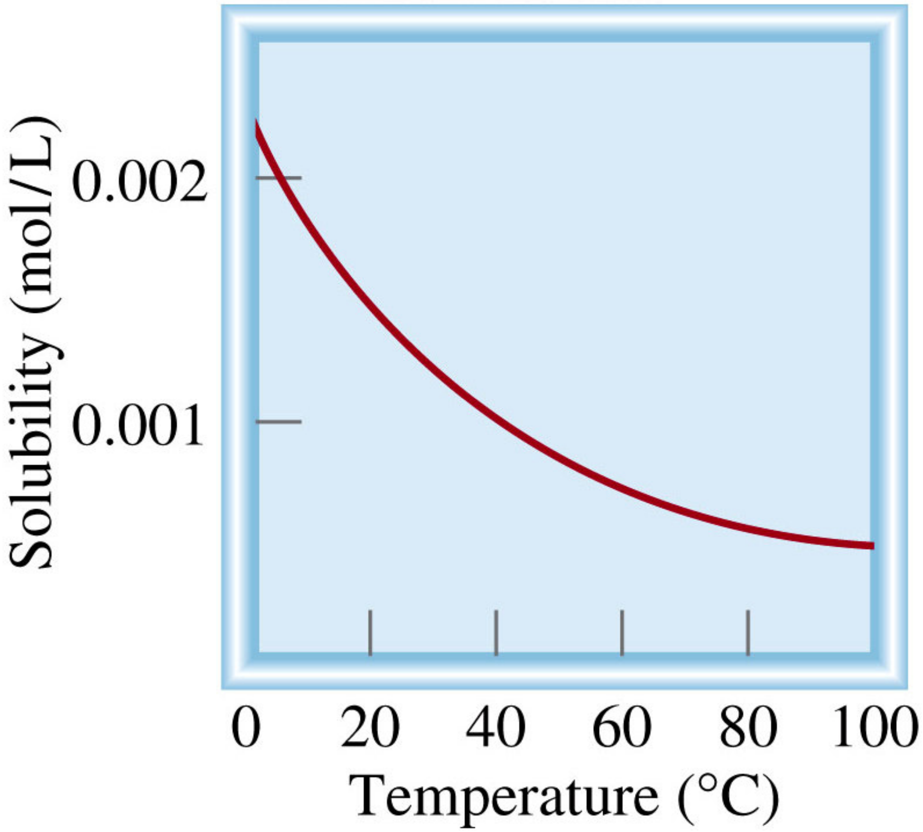
Suppose you have 90 g KNO_3 contaminated with 10 g NaCl.

Fractional crystallization:

1. Dissolve sample in 100 mL of water at 60^0C
2. Cool solution to 0^0C
3. All NaCl will stay in solution (s = 34.2g/100g)
4. 78 g of PURE KNO_3 will precipitate (s = 12 g/100g). 90 g – 12 g = 78 g

Temperature and Solubility

O_2 gas solubility and temperature



solubility usually decreases with increasing temperature

Pressure and Solubility of Gases

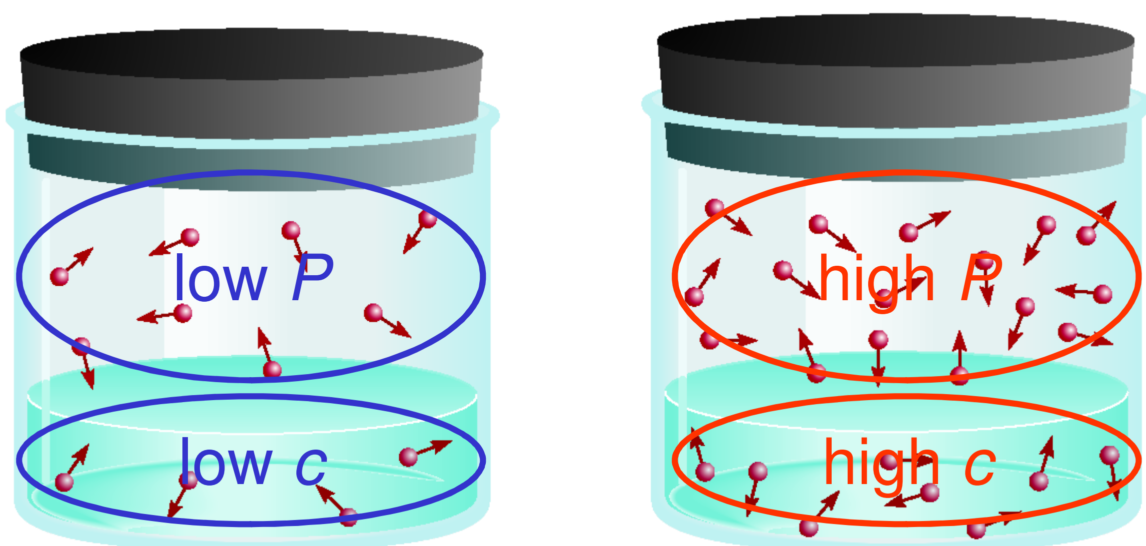
The solubility of a gas in a liquid is proportional to the pressure of the gas over the solution (***Henry's law***).

$$c = kP$$

c is the concentration (*M*) of the dissolved gas

P is the pressure of the gas over the solution

k is a constant for each gas (mol/L•atm) that depends only on temperature



Chemistry In Action: The Killer Lake

8/21/86
CO_2 Cloud Released
1700 Casualties

Trigger?

- **earthquake**
- **landslide**
- **strong Winds**

Lake Nyos, West Africa

Colligative Properties of Nonelectrolyte Solutions

Colligative properties are properties that depend only on the **number** of solute particles in solution and not on the **nature** of the solute particles.

Vapor-Pressure Lowering

$$P_1 = X_1 P_1^0$$

Raoult's law

P_1^0 = vapor pressure of **pure** solvent

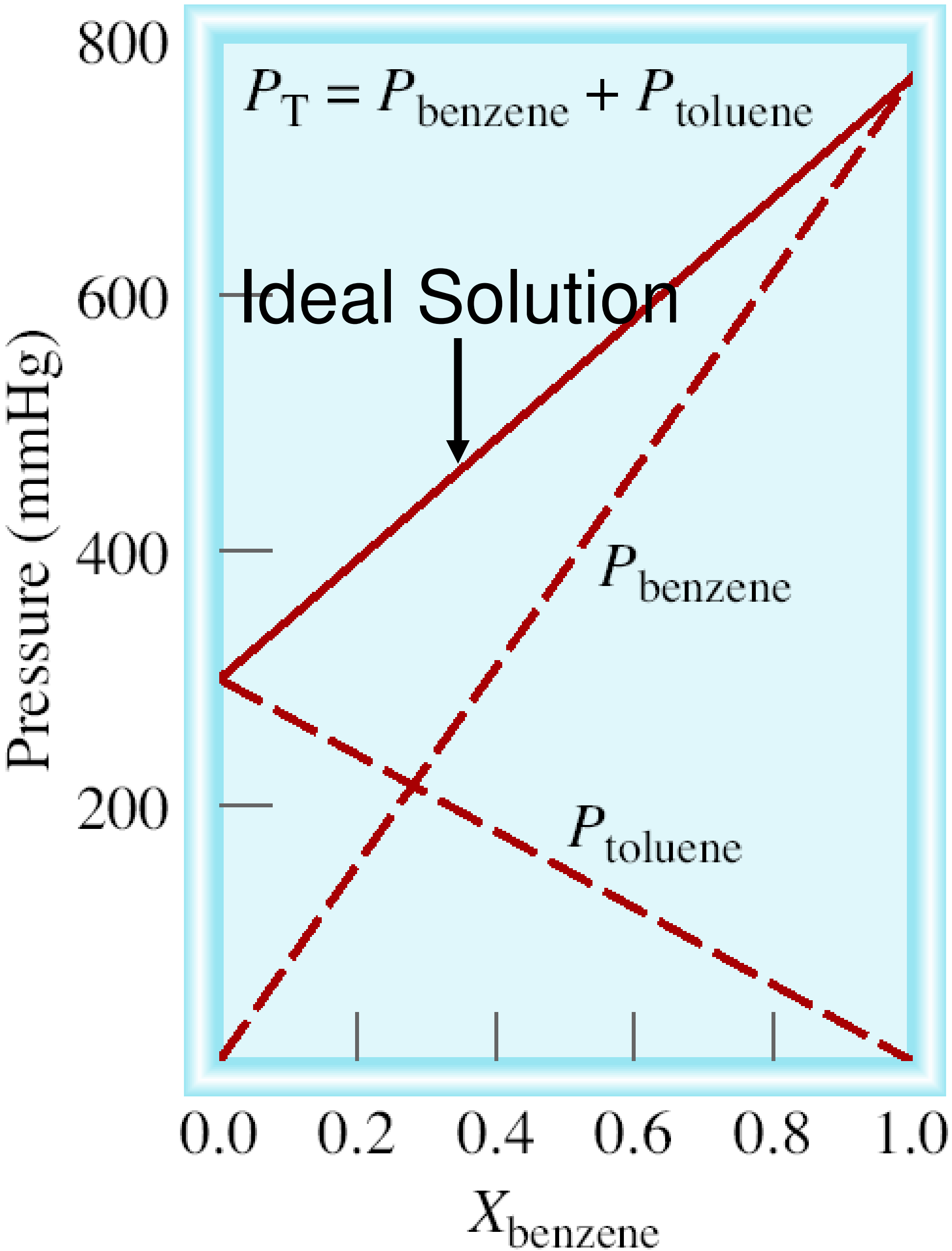
X_1 = mole fraction of the solvent

If the solution contains only one solute:

$$X_1 = 1 - X_2$$

$$P_1^0 - P_1 = \Delta P = X_2 P_1^0$$

X_2 = mole fraction of the solute



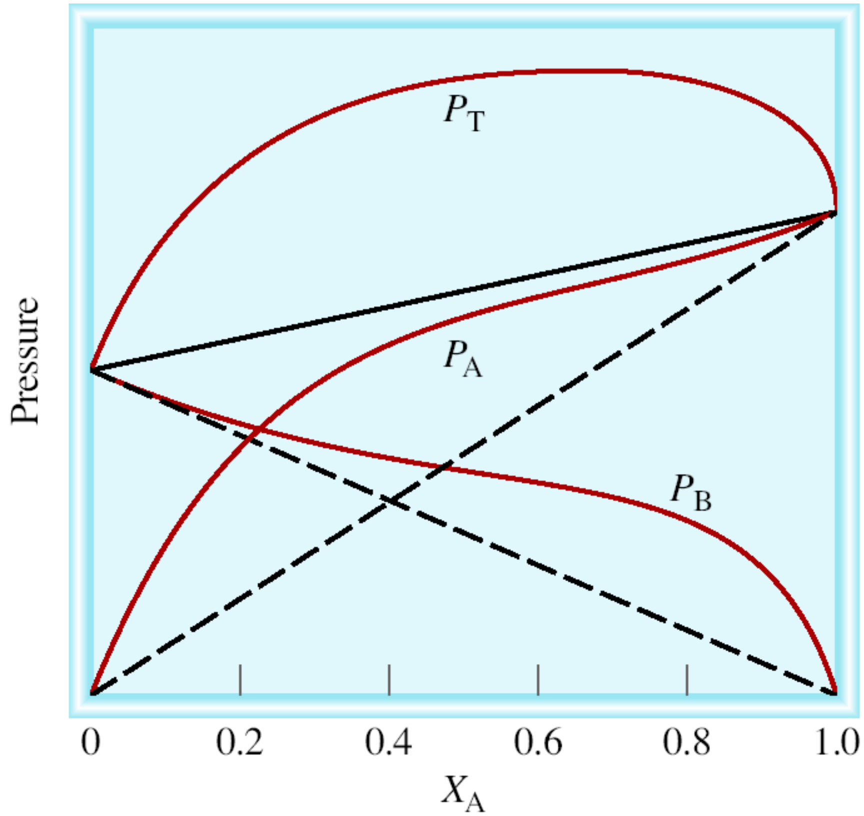
$$P_A = X_A P_A^0$$

$$P_B = X_B P_B^0$$

$$P_T = P_A + P_B$$

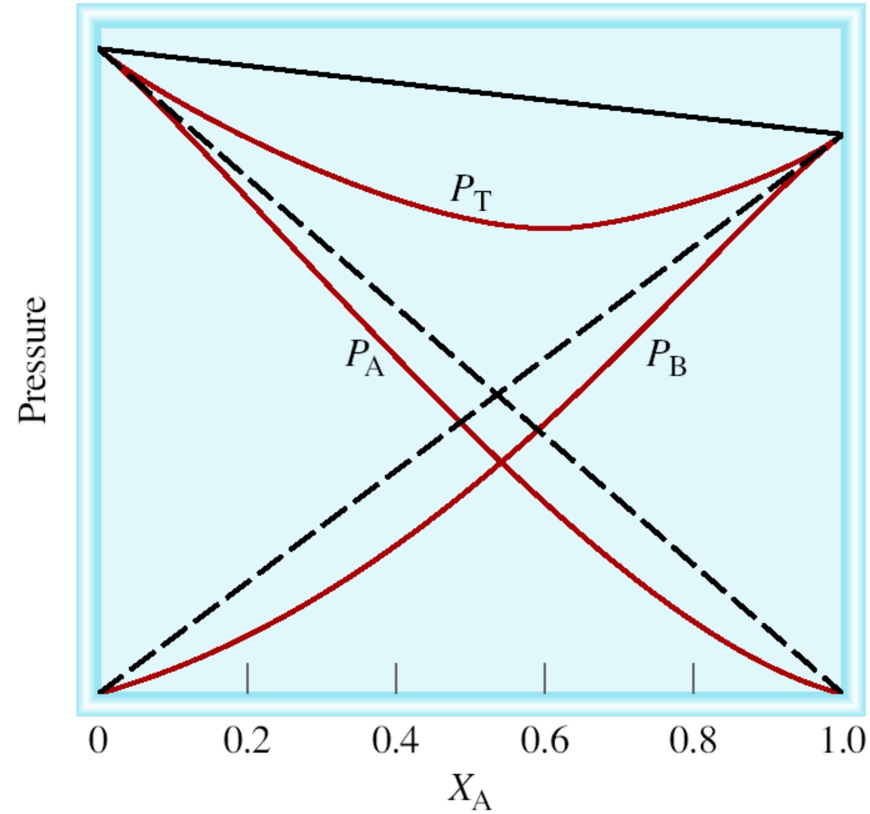
$$P_T = X_A P_A^0 + X_B P_B^0$$

P_T is greater than predicted by Raoults's law



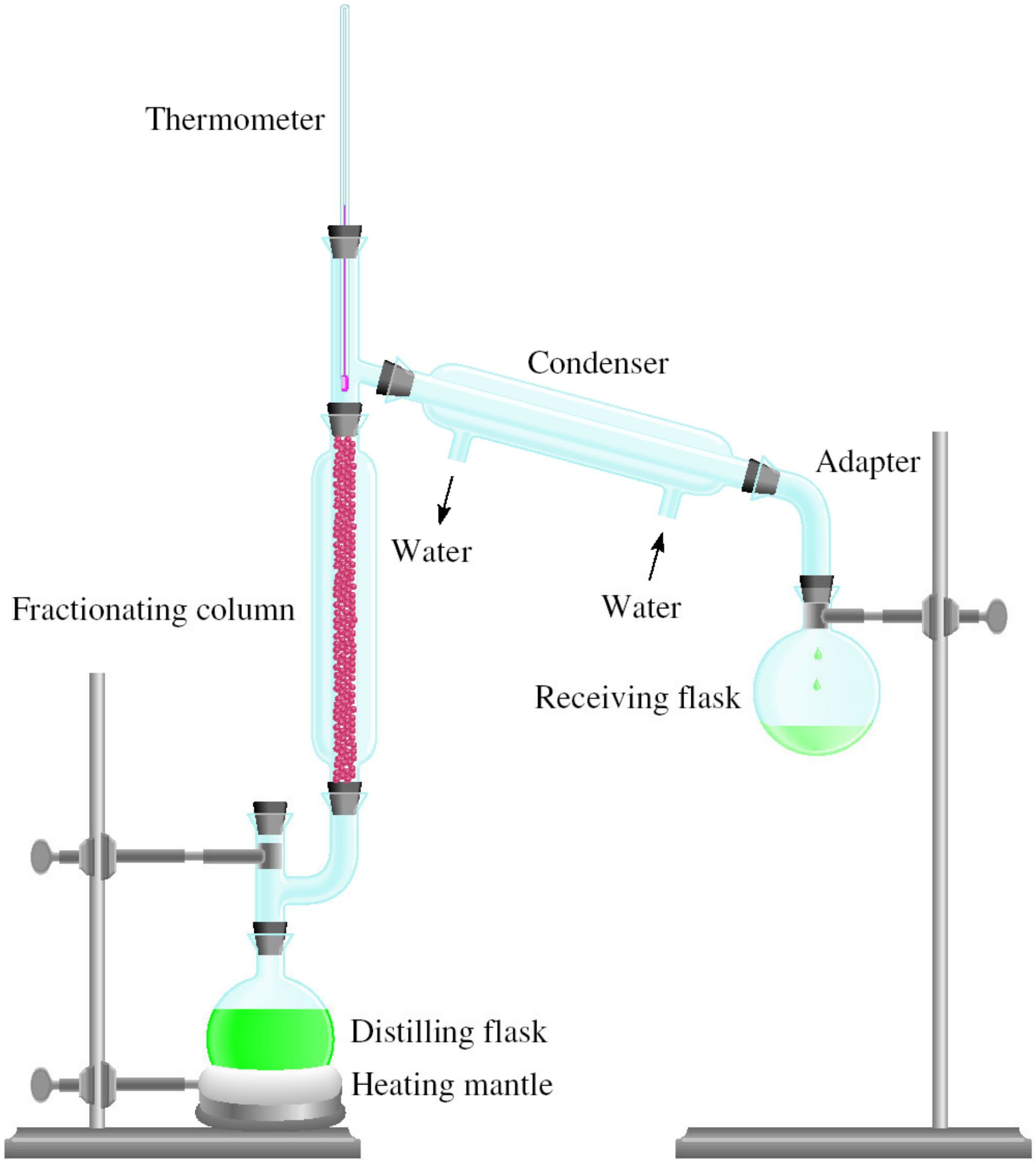
Force A-B < Force A-A & Force B-B

P_T is less than predicted by Raoults's law

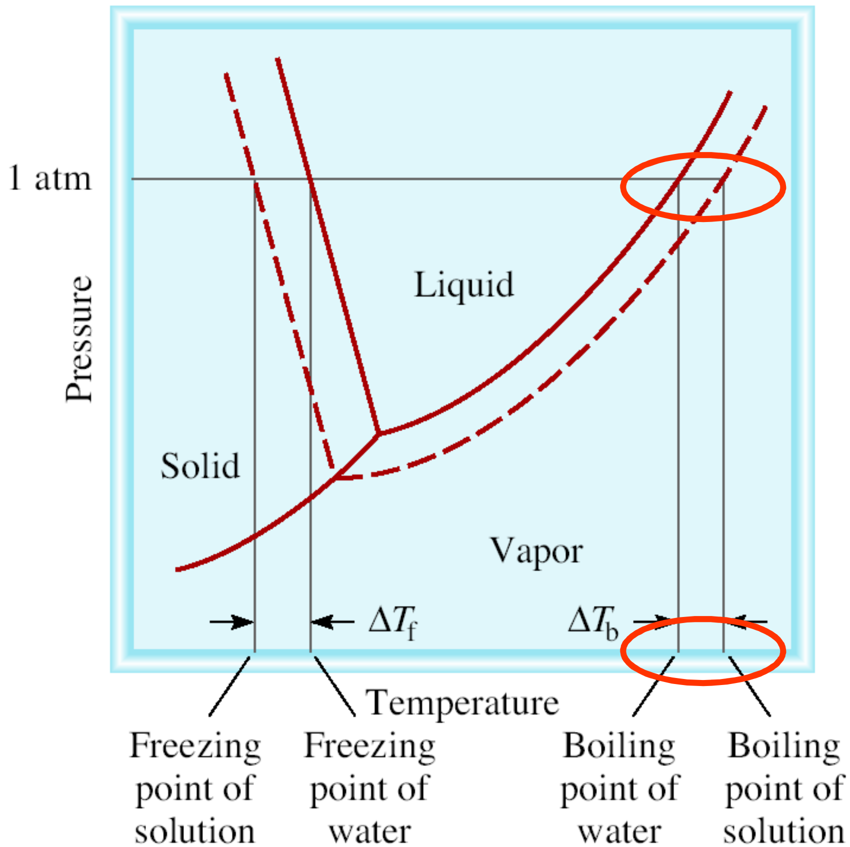


Force A-B > Force A-A & Force B-B

Fractional Distillation Apparatus



Boiling-Point Elevation



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

T_b^0 is the boiling point of the pure solvent

T_b is the boiling point of the solution

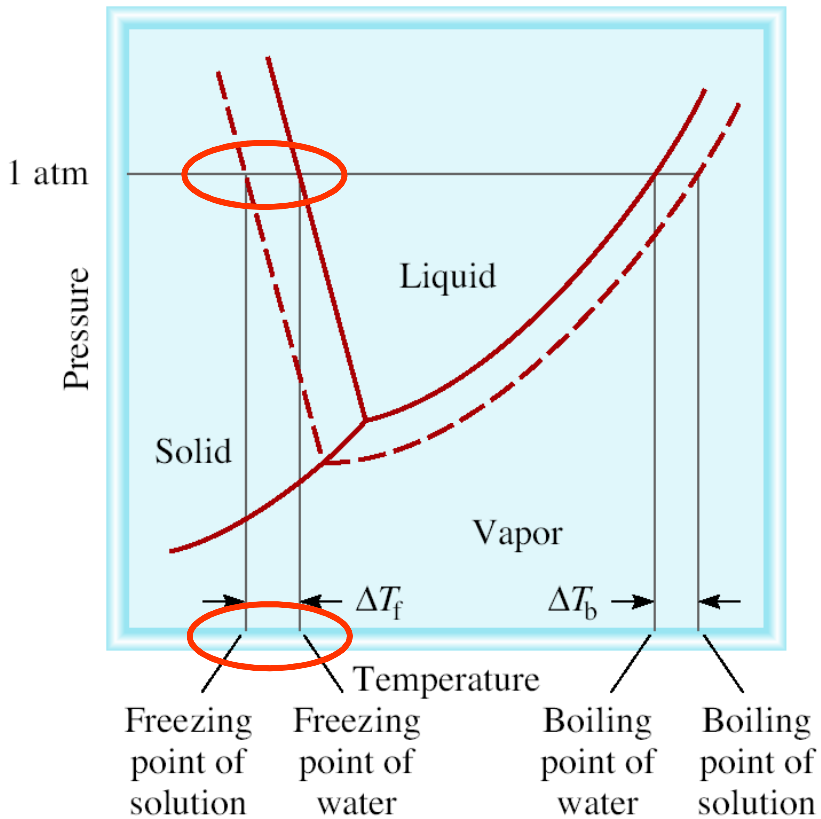
$T_b > T_b^0$ $\Delta T_b > 0$

$$\boxed{\Delta T_b = K_b\, m}$$

m is the molality of the solution

K_b is the molal boiling-point elevation constant (^{0}C/m) for a given solvent

Freezing-Point Depression



$$\Delta T_f = T_f^0 - T_f$$

T_f^0 is the freezing point of the pure solvent

T_f is the freezing point of the solution

$T_f^0 > T_f \qquad \Delta T_f > 0$

$$\boxed{\Delta T_f = K_f\, m}$$

m is the molality of the solution

K_f is the molal freezing-point depression constant (^{0}C/m) for a given solvent

TABLE 12.2 Molal Boiling-Point Elevation and Freezing-Point Depression Constants of Several Common Liquids

Solvent	Normal Freezing Point (°C)*	K_f (°C/*m*)	Normal Boiling Point (°C)*	K_b (°C/*m*)
Water	0	1.86	100	0.52
Benzene	5.5	5.12	80.1	2.53
Ethanol	−117.3	1.99	78.4	1.22
Acetic acid	16.6	3.90	117.9	2.93
Cyclohexane	6.6	20.0	80.7	2.79

*Measured at 1 atm.

What is the freezing point of a solution containing 478 g of ethylene glycol (antifreeze) in 3202 g of water? The molar mass of ethylene glycol is 62.01 g.

$$\Delta T_f = K_f\, m \qquad K_f \text{ water} = 1.86\ ^{o}\mathrm{C}/m$$

$$\boldsymbol{m} = \frac{\text{moles of solute}}{\text{mass of solvent (kg)}} = \frac{478 \text{ g} \times \dfrac{1 \text{ mol}}{62.01 \text{ g}}}{3.202 \text{ kg solvent}} = 2.41\ m$$

$$\Delta T_f = K_f\, m = 1.86\ ^{o}\mathrm{C}/m \times 2.41\ m = 4.48\ ^{o}\mathrm{C}$$

$$\Delta T_f = T_f^0 - T_f$$

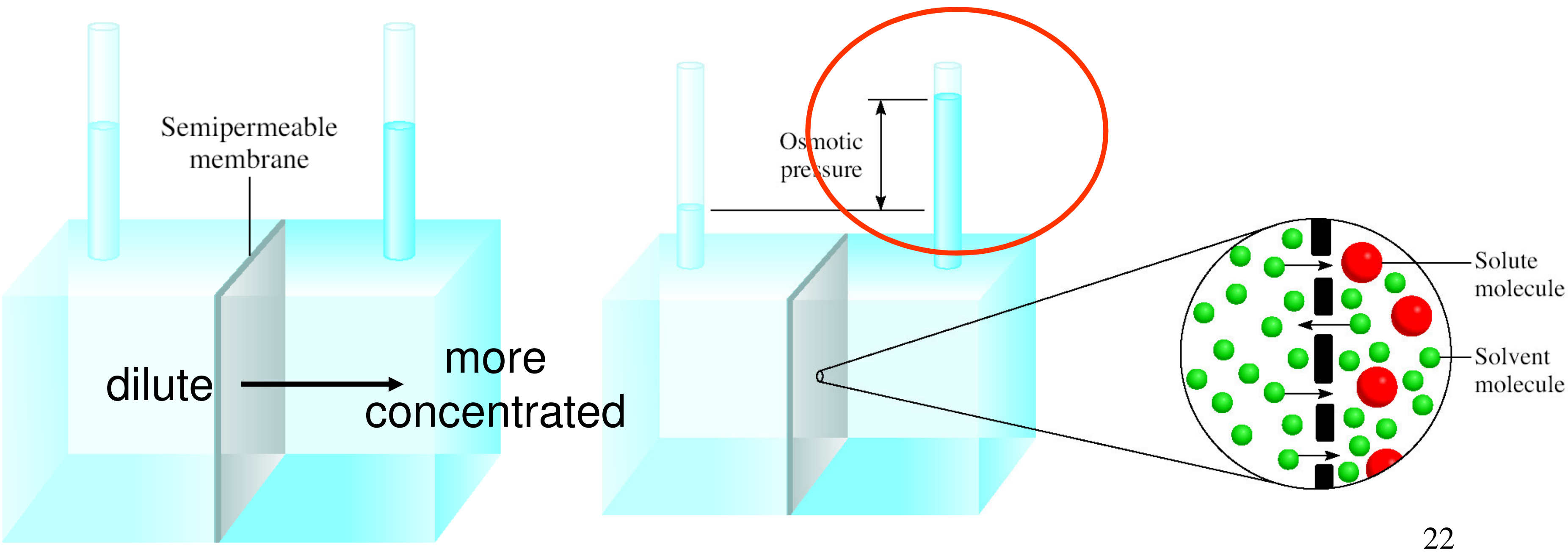
$$T_f = T_f^0 - \Delta T_f = 0.00\ ^{o}\mathrm{C} - 4.48\ ^{o}\mathrm{C} = -4.48\ ^{o}\mathrm{C}$$

Osmotic Pressure (π)

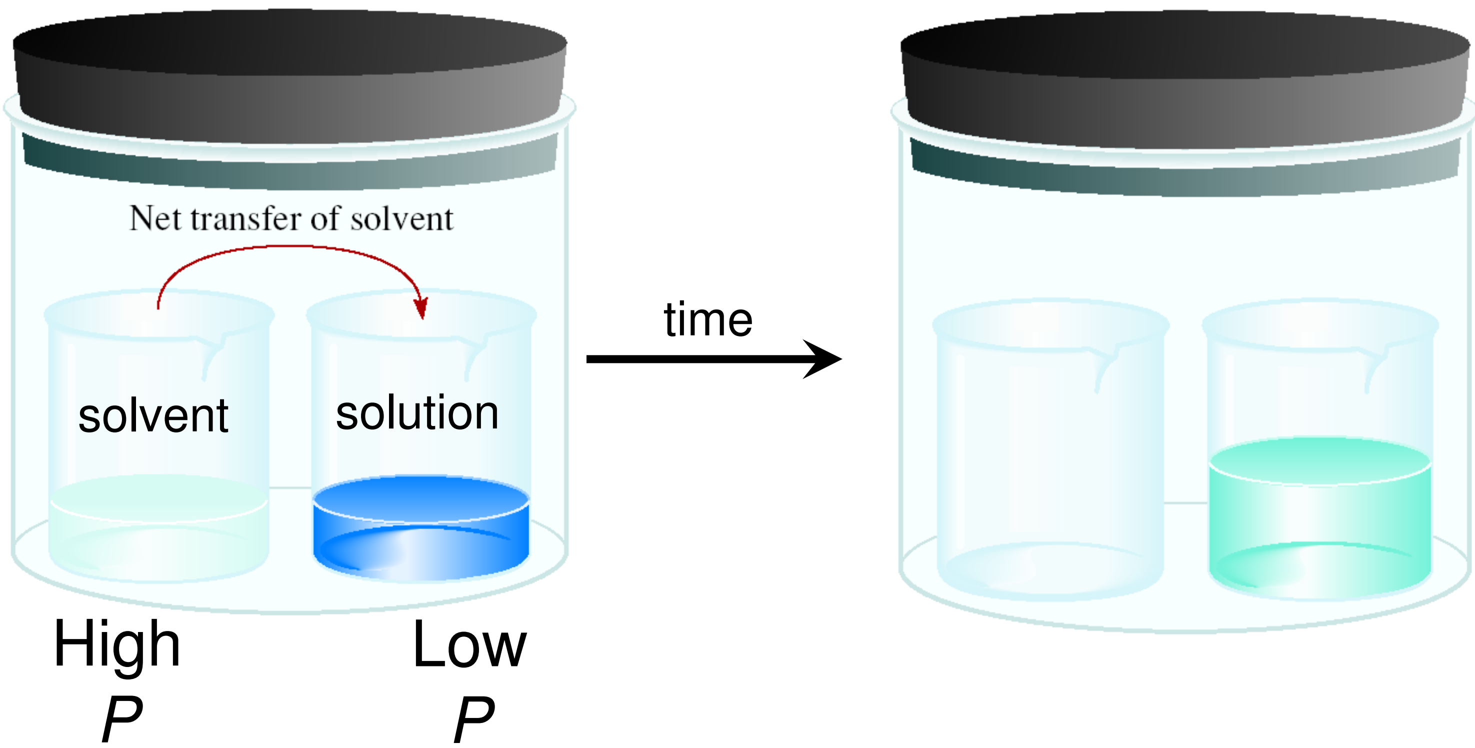
Osmosis is the selective passage of solvent molecules through a porous membrane from a dilute solution to a more concentrated one.

A ***semipermeable membrane*** allows the passage of solvent molecules but blocks the passage of solute molecules.

Osmotic pressure (π) is the pressure required to stop osmosis.



Osmotic Pressure (π)



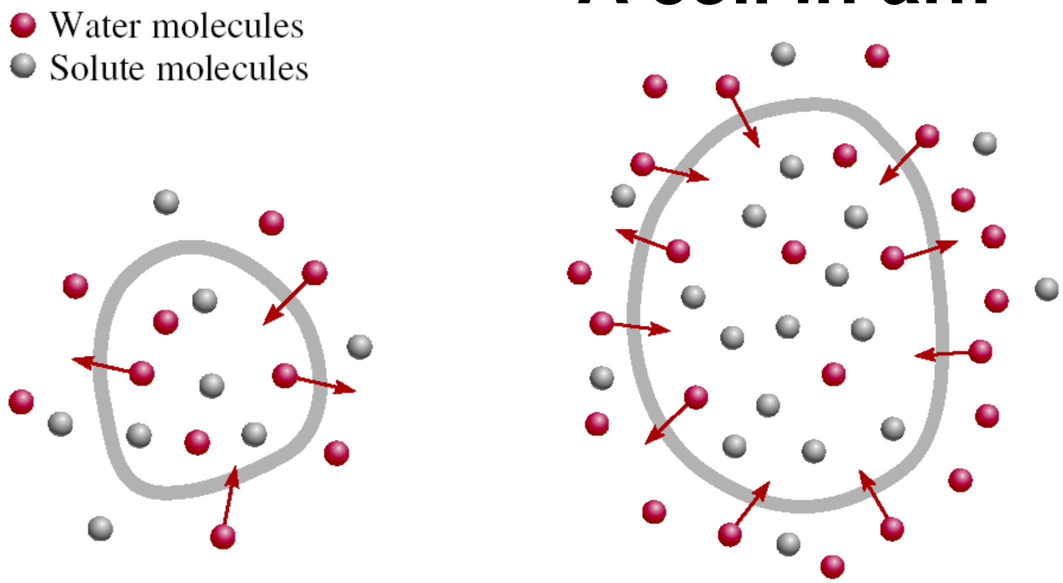
$$\pi = MRT$$

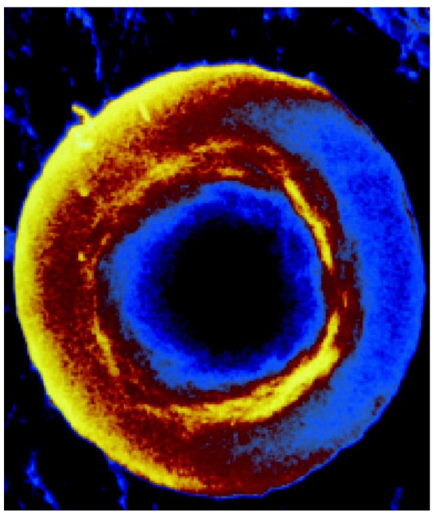
M is the molarity of the solution

R is the gas constant

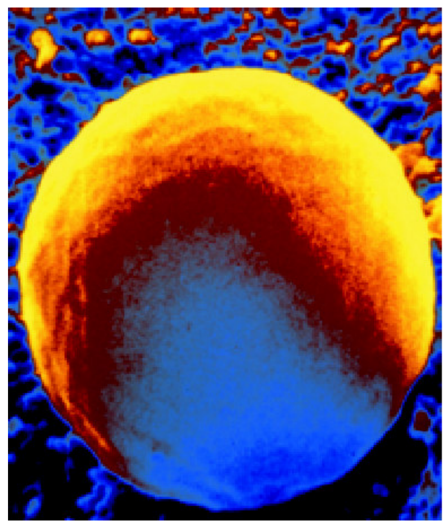
T is the temperature (in K)

A cell in an:

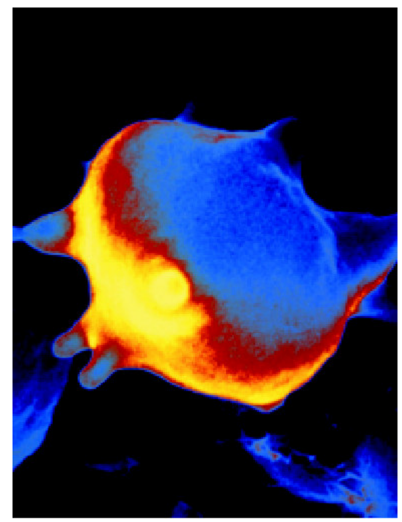




isotonic
solution



hypotonic
solution



hypertonic
solution

Colligative Properties of Nonelectrolyte Solutions

Colligative properties are properties that depend only on the **number** of solute particles in solution and not on the **nature** of the solute particles.

Vapor-Pressure Lowering $P_1 = X_1 P_1^0$

Boiling-Point Elevation $\Delta T_b = K_b m$

Freezing-Point Depression $\Delta T_f = K_f m$

Osmotic Pressure (π) $\pi = MRT$

Colligative Properties of Electrolyte Solutions

0.1 *m* NaCl solution ⟶ 0.1 *m* Na^+ ions & 0.1 *m* Cl^- ions

Colligative properties are properties that depend only on the **number** of solute particles in solution and not on the **nature** of the solute particles.

0.1 *m* NaCl solution ⟶ 0.2 *m* ions in solution

$$\textbf{\textit{van't Hoff factor (i)}} = \frac{\text{actual number of particles in soln after dissociation}}{\text{number of formula units initially dissolved in soln}}$$

	i should be
nonelectrolytes	1
NaCl	2
$CaCl_2$	3

Colligative Properties of Electrolyte Solutions

Boiling-Point Elevation $\Delta T_b = i K_b m$

Freezing-Point Depression $\Delta T_f = i K_f m$

Osmotic Pressure (π) $\pi = iMRT$

TABLE 12.3 The van't Hoff Factor of 0.0500 *M* Electrolyte Solutions at 25°C

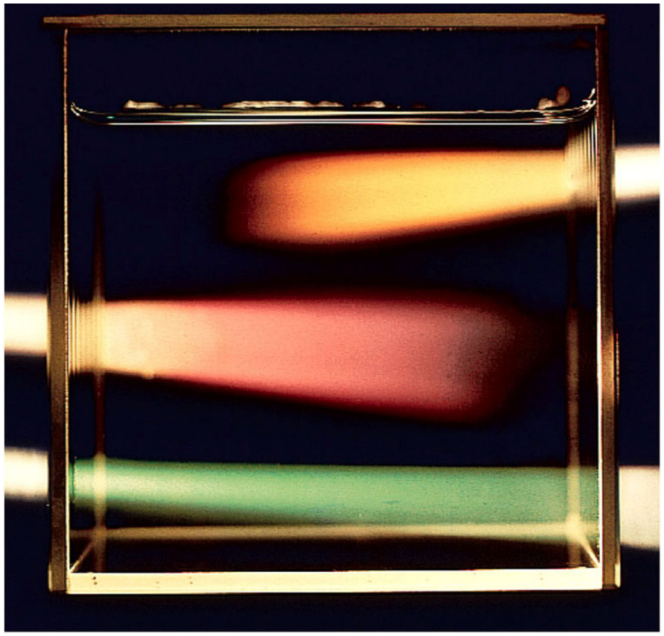
Electrolyte	*i* (Measured)	*i* (Calculated)
Sucrose*	1.0	1.0
HCl	1.9	2.0
NaCl	1.9	2.0
$MgSO_4$	1.3	2.0
$MgCl_2$	2.7	3.0
$FeCl_3$	3.4	4.0

*Sucrose is a nonelectrolyte. It is listed here for comparison only.

A ***colloid*** is a dispersion of particles of one substance throughout a dispersing medium of another substance.

<u>Colloid versus solution</u>

- collodial particles are much larger than solute molecules
- collodial suspension is not as homogeneous as a solution
- colloids exhibit the Tyndall effect



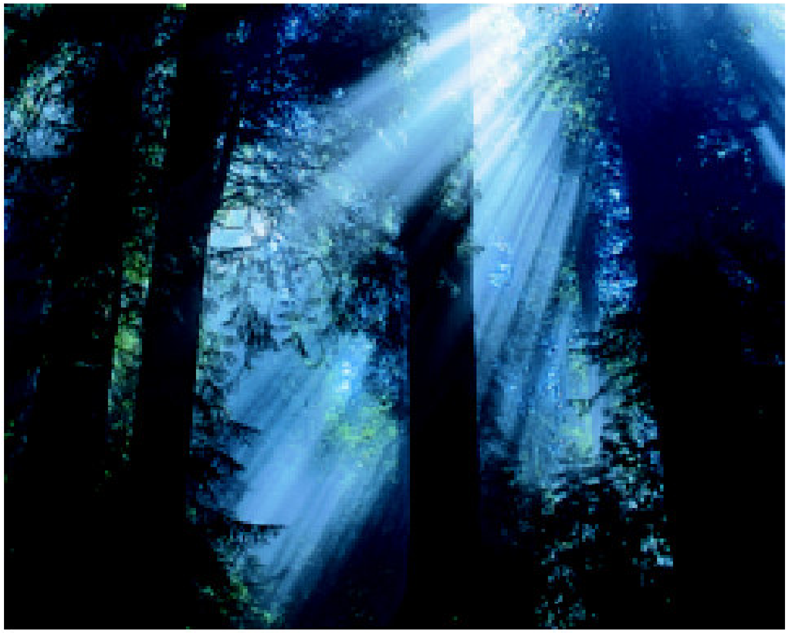
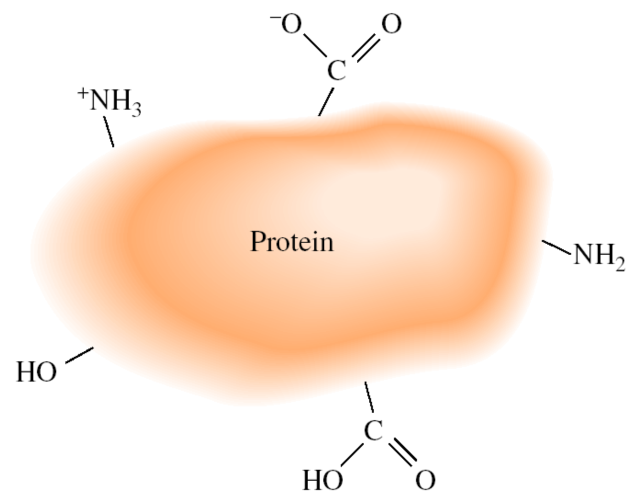


TABLE 12.4 Types of Colloids

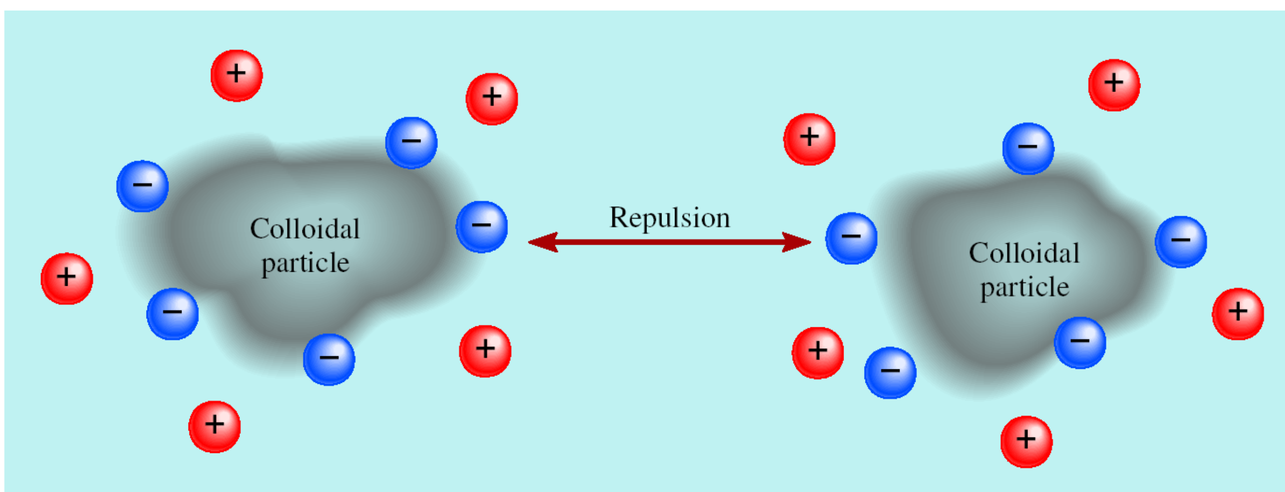
Dispersing Medium	Dispersed Phase	Name	Example
Gas	Liquid	Aerosol	Fog, mist
Gas	Solid	Aerosol	Smoke
Liquid	Gas	Foam	Whipped cream
Liquid	Liquid	Emulsion	Mayonnaise
Liquid	Solid	Sol	Milk of magnesia
Solid	Gas	Foam	Plastic foams
Solid	Liquid	Gel	Jelly, butter
Solid	Solid	Solid sol	Certain alloys (steel), opal

Hydrophilic and Hydrophobic Colloids

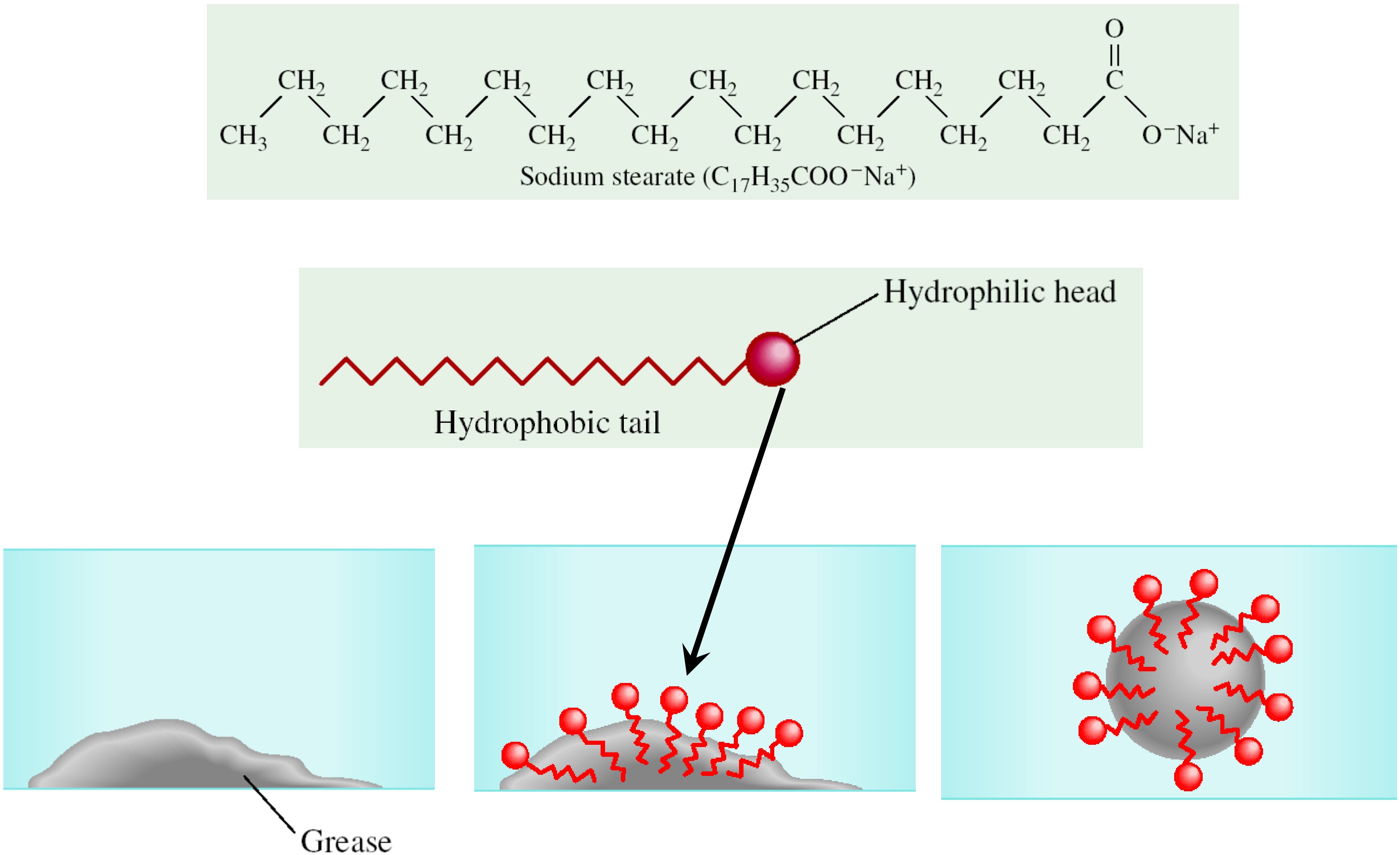
Hydrophilic: water-loving
Hydrophobic: water-fearing



Stabilization of a hydrophobic colloid



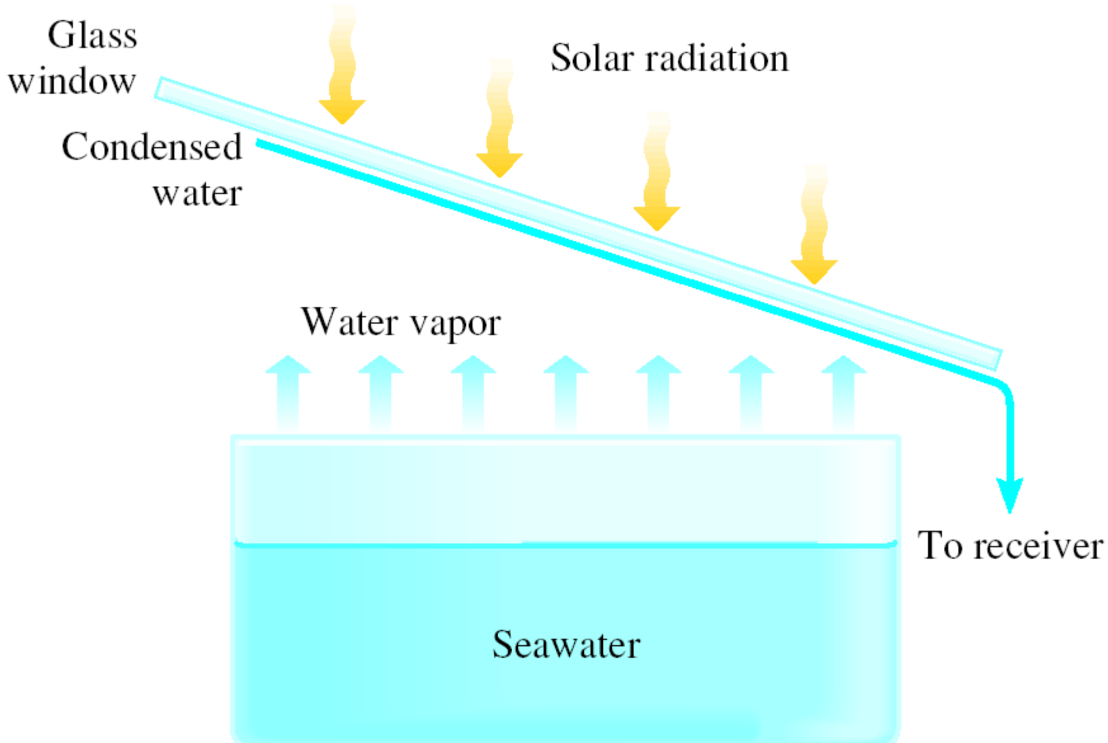
The Cleansing Action of Soap



Chemistry In Action: Desalination

Composition of Seawater

Ions	g/kg of Seawater
Chloride (Cl^-)	19.35
Sodium (Na^+)	10.76
Sulfate (SO_4^{2-})	2.71
Magnesium (Mg^{2+})	1.29
Calcium (Ca^{2+})	0.41
Potassium (K^+)	0.39
Bicarbonate (HCO_3^-)	0.14



Chemistry In Action:
Reverse Osmosis