SOLUTIONS
3: COLLIGATIVE PROPERTIES

Dr. Sapna Gupta

SOLUTIONS: COLLIGATIVE PROPERTIES

Properties of solutions are not the same as pure solvents.

- Number of solute particles will change vapor pressure (boiling point) and freezing point.
- There are two kinds of solute: volatile (evaporate all the time) and nonvolatile (do not evaporate) solutes. Both behave differently.
- **Raoult's Law**: Gives the quantitative expressions on vapor pressure:
  - VP will be lowered if solute is non-volatile: P is new VP, P^0 is original VP and χ is mol fraction of solute.

$$P_1 = \chi_1 P_1^0$$

  - VP will the sum of VP solute and solvent if solute is volatile: X_A and X_B are mol fractions of both components.

$$P_T = \chi_A P_A^0 + \chi_B P_B^0$$

EXAMPLE 1: VAPOR PRESSURE

Calculate the vapor pressure of a solution made by dissolving 115 g of urea, a nonvolatile solute, [$(NH_2)_2CO$; molar mass = 60.06 g/mol] in 485 g of water at 25°C. (At 25°C, P_{H2O} = 23.8 mmHg)

Answer: Use Raoult's equation.

$$P_{H_2O} = \chi_{H_2O} P^0_{H_2O}$$

$$\text{mol}_{H_2O} = 485\ \text{g} \times \frac{\text{mol}}{18.02\ \ \text{g}} = 26.91\ \text{mol}$$

$$\text{mol}_{\text{urea}} = 115\ \text{g} \times \frac{\text{mol}}{60.06\ \text{g}} = 1.915\ \text{mol}$$

$$\chi_{H_2O} = \frac{26.91\ \text{mol}}{26.91\ \text{mol} + 1.915\ \text{mol}} = 0.9336$$

$$P_{H_2O} = 0.9392 \times 23.8\ \text{mmHg} = \mathbf{22.2\ mmHg}$$

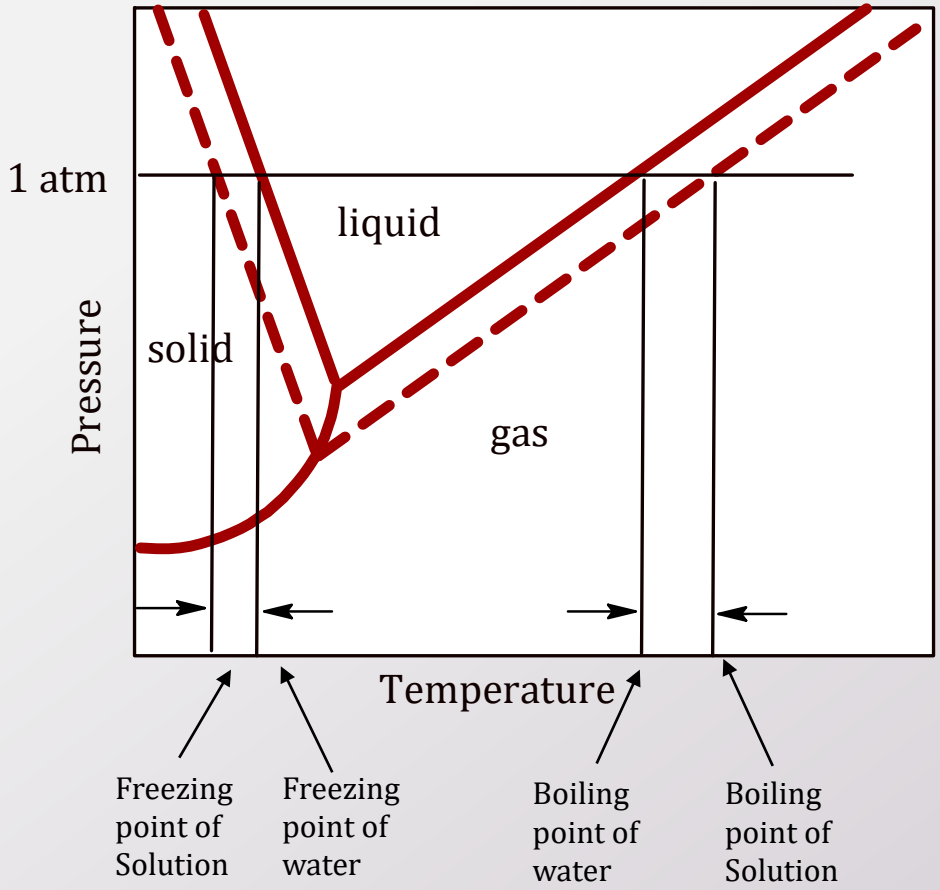
BOILING POINT ELEVATION

Boiling point of solvent will be raised if a nonvolatile solute is dissolved in it.

- Boiling point elevation will be directly proportional to molal concentration.

$$\Delta T_b = K_b m$$

- K_b is the molal boiling point elevation constant.



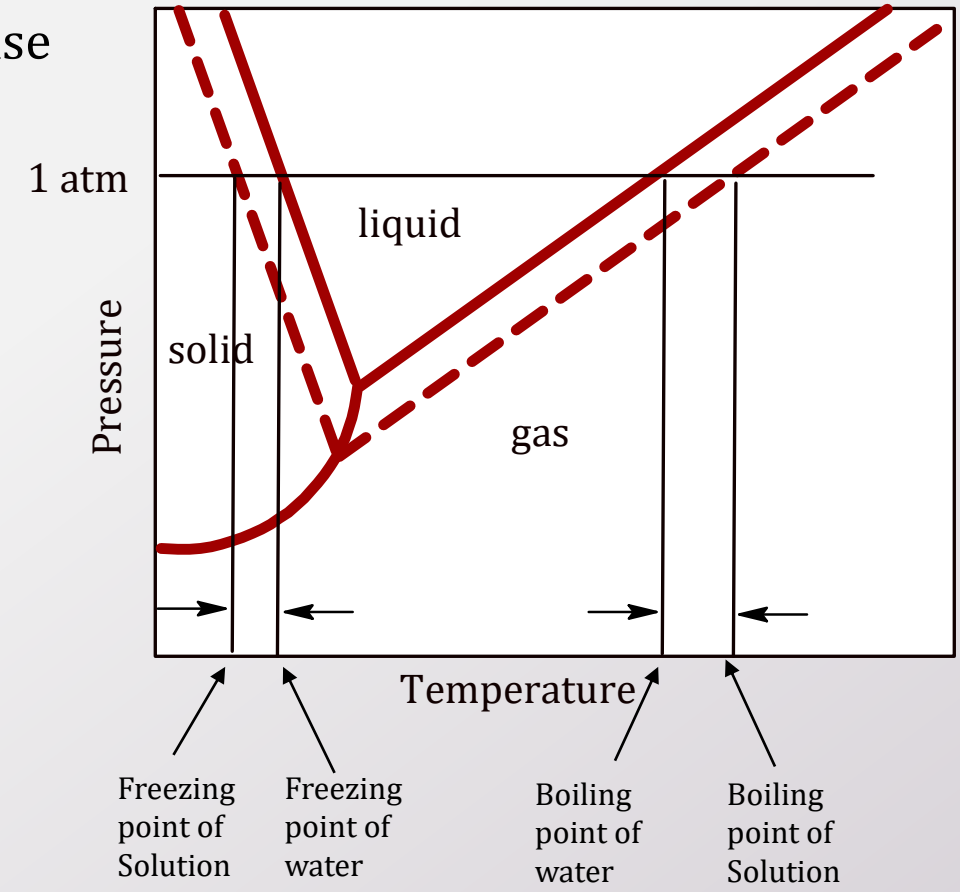
FREEZING POINT DEPRESSION

Freezing point of a solvent will decrease when a solute is dissolved in it.

- Freezing point lowering will be directly proportional to molal concentration.

$$\Delta T_f = -K_f m$$

- K_f is the molal freezing point depression constant.



FREEZING AND BOILING PT. CONSTANTS

Some freezing point depressions and boiling point elevations constants.

Solvent	Normal boiling point	K_b (°C/*m*)	Normal freezing point (°C)	K_f (°C/*m*)
Water	100.0	0.52	0.0	1.86
Benzene	80.1	2.53	5.5	5.12
Ethanol	78.4	1.22	-117.3	1.99
Acetic acid	117.9	2.93	16.6	3.90
Cyclohexane	80.7	2.79	6.6	20.0

EXAMPLE 2: FPT. AND BPT. CHANGES

Calculate the new a) the freezing point and b) the boiling point of a solution containing 268 g of ethylene glycol (MW: 62.07 g/mol) and 1015 g of water. K_b and K_f for water are 0.512°C/m and 1.86°C/m, respectively.

Answer: Find molality of solution and use the formulas to calculate changes.

$$\text{mol ethylene glycol} = 268\ g \times \frac{\text{mol}}{62.07\ \text{g}} = 4.318\ \text{mol solute}$$

$$m = \frac{\text{mols of solute}}{\text{kg of solvent}}$$

$$m = 4.318\ \text{mol} \times \frac{1}{1015\ \text{g}} \times \frac{10^3\text{g}}{\text{kg}} = 4.254\ m$$

$$\Delta T_f = -K_f m$$

$$\Delta T_f = \frac{1.86^o C}{m} \times 4.254\ m = -7.91\ ^o\text{C}$$

$$-7.91\ ^o\text{C} = 0.00\ ^o\text{C} - T_f$$

$$\boldsymbol{T_f = -7.91\ ^o\text{C}}$$

$$\Delta T_b = K_b m$$

$$\Delta T_b = \frac{0.512^o\ C}{m} \times 4.254\ m = 2.18\ ^o\text{C}$$

$$2.18\ ^o\text{C} = T_b - 100.00\ ^o\text{C}$$

$$\boldsymbol{T_b = 102.2\ ^o\text{C}}$$

EXAMPLE 3: CALCULATION OF MOLAR MASS USING BOILING POINT ELEVATION

A 11.2-g sample of sulfur was dissolved in 40.0 g of carbon disulfide. The boiling-point elevation of carbon disulfide was found to be 2.63°C. What is the molar mass of the sulfur? What is the empirical formula of the molecular sulfur? (K_b, for carbon disulfide is 2.40°C/m.)

Answer:

Strategy: Calc. moles of solute -> find mm using g solute -> find emp formula

$$\Delta T_b = K_b m \qquad m = \frac{\Delta T_b}{K_b} = \frac{2.63°C}{2.40\,\frac{°C}{m}} = 1.096\ m$$

$$m = \frac{\text{mol solute}}{\text{kg solvent}}$$

$$\begin{aligned}\text{mol solute} &= m \times \text{kg solvent} \\ &= 1.096\ mol/kg \times 0.0400\ \text{kg} \\ &= 0.04383\ \text{mol}\end{aligned}$$

$$\text{Molar mass} = \frac{11.2\ \text{g}}{0.04383\ \text{mol}} = \boxed{255.5\ \text{g/mol}}$$

empirical formula of sulfur = S

and atomic mass is 32.065 g/mol

$$n = \frac{255.5}{32.065} \approx 8$$

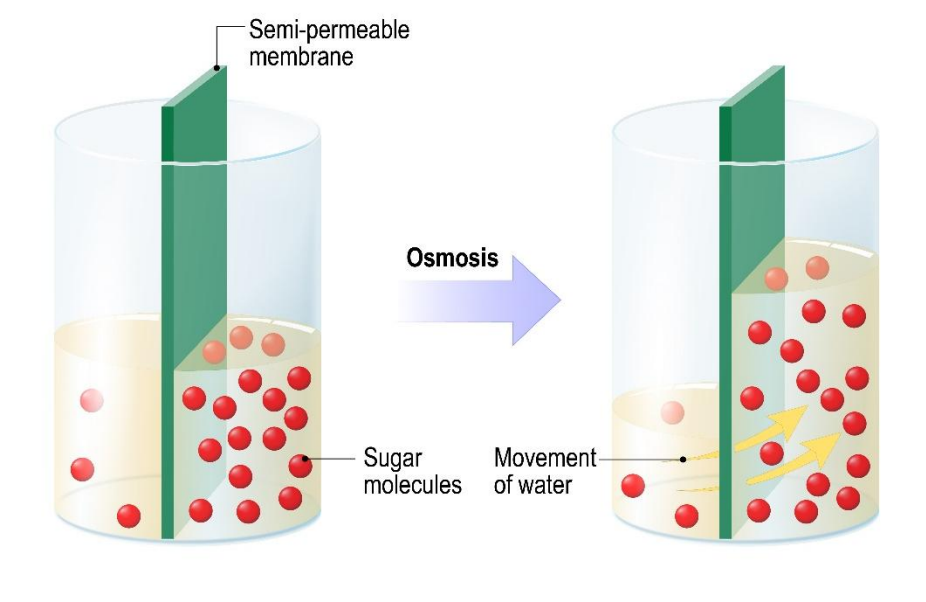
$\boxed{\text{Sulfur} = S_8}$

OSMOSIS

Osmosis is the movement of solvent molecules through a semipermeable membrane.

- Osmotic pressure, π, is the pressure that just stops osmosis. Osmotic pressure is a colligative property of a solution.

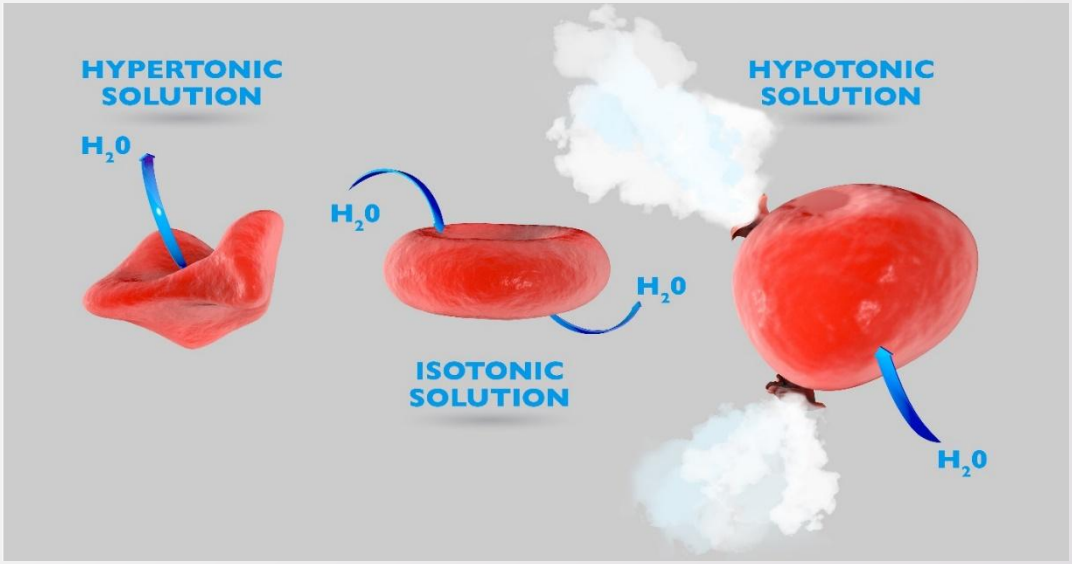
$$\pi = MRT$$ (R = gas const.; M = molarity and T = temp in Kelvin)



 Shutterstock Image

OSMOSIS - APPLICATION

Osmosis is key in water transport in blood and in water transport in plant.



Shutterstock Image

A	B	C
Hypertonic solution	Isotonic solution	Hypotonic solution
Water flows out of cell.		Water flows into cell.
Crenation		Hemolysis

EXAMPLE 4: CALCULATION OF MOLAR MASS USING OSMOTIC PRESSURE

A solution made by dissolving 25.0 mg of insulin in 5.00 mL of water has an osmotic pressure of 15.5 mmHg at 25°C. Calculate the molar mass of insulin. (Assume that there is no change in volume when the insulin is added to the water and that insulin is a non-dissociating solute.)

Answer:

Strategy: calculate Molarity -> calculate moles -> calculate molar mass

1) Convert units: $\pi = 15..5\ \text{mmHg} \times \frac{\text{atm}}{760\ \text{mmHg}} = 2.039\text{x}10^{-2}\text{atm}$ $\quad T = 25+273 = 298\text{K}$

2) Find Molarity using osmotic pressure equation: $\boxed{\pi = MRT}$

$$M = \frac{\pi}{RT} = 2.039\ \text{x}10^{-2}\text{atm} \times \frac{\text{mol} \cdot \text{K}}{0.0821\ \text{L} \cdot \text{atm}} \times \frac{1}{298\ \text{K}} = 8.338\ x\ 10^{-4}\ mol/L$$

3) Find Mols using Molarity (M = mol/L) $\quad \text{mol} = \frac{8.34\ x\ 10^{-4} mol}{L} \times \frac{5\ x\ 10^{-3}\text{L}}{} = 4.169\ \text{x}10^{-6}\text{mol}$

4) Find molar mass $\quad M = \frac{25.0 \times 10^{-3}\ g}{4.169 \times 10^{-6}\text{mol}} = \boxed{\mathbf{6.00\ x\ 10^{3}\ g/mol}}$

VAN'T HOFF FACTOR: SOLUTIONS OF ELECTROLYTES

Dissociation of strong and weak electrolytes affects the number of particles in a solution. Strong electrolytes dissociate completely while weak electrolytes have incomplete dissociation, hence not known how many particles are in solution.

Van't Hoft factor (i) – accounts for the effect of dissociation and helps to determine the effect of dissolved particles on colligative properties.

$$i = \frac{\text{actual number of particles in solution after dissociation}}{\text{number of formula units initially dissolved in solution}}$$

For a nonelectrolyte, the van't Hoff factor is 1. For e.g., one molecule of methanol, CH_3OH, will give only 1 dissolved molecule/particle because methanol does not dissociate in water.

The modified equations for colligative properties are:

$$\Delta T_f = iK_f m \qquad \Delta T_b = iK_b m \qquad \pi = iMRT$$

EXAMPLE 5: VAN'T HOFF FACTOR

Estimate the van't Hoff factor of the following solutions.

1.00 M HCl, 1.00 M NaCl, 1.00 M $Ca(NO_3)_2$, 1.00 M $C_6H_{12}O_6$ (glucose), 1.00 CH_3COOH (acetic acid)

Answer:

***Strategy*:** Determine the dissociates of all the solutions and then see how many particles are in solution.

HCl	⟶	$H^+ + Cl^-$	2 particles; $i = 2$
NaCl	⟶	$Na^+ + Cl^-$	2 particles; $i = 2$
$Ca(NO_3)_2$	⟶	$Ca^{2+} + 2NO_3^-$	3 particles; $i = 3$
$C_6H_{12}O_6$		no dissociation	1 particles; $i = 1$
CH_3COOH		weak dissociation	< 2 particles; i = between 1 and 2

EXAMPLE 6: VAN'T HOFF FACTOR

The freezing-point depression of a 0.100 m $MgSO_4$ solution is 0.225°C. Determine the experimental van't Hoff factor of $MgSO_4$ at this concentration.

Answer:

One way:

Calculate for i directly

$$\Delta T_f = iK_f m$$

$$0.225^oC = i \times \frac{1.86^oC}{m} \text{ x } 0.100\ m$$

$$\boldsymbol{i = 1.21}$$

Second way:

Compare the freezing points

$$\Delta T_f = \frac{1.86^oC}{m} \times\ 0.100\ m = 0.186^oC$$

$$i = \frac{0.225^oC}{0.186^oC} = \mathbf{1.21}$$

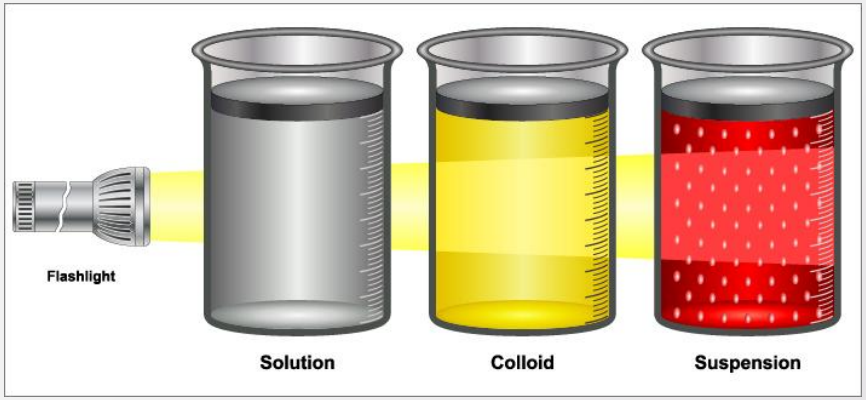
COLLOID

- There are two kinds of solutions: true solution (homogeneous solution) and colloids: which is a dispersion of particles in a solvent.
- It is an intermediate between homo and heterogeneous mixture.
- Particle size – 10^3-10^6 pm
- Examples: aerosols, foam, emulsions, sols, gels etc.

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	Styrofoam
Solid	Liquid	Gel	Jelly, butter
Solid	Solid	Solid sol	Alloys

TYNDALL EFFECT

- One can tell there is a true solution or colloid by shining light through the solution.
- A true solution will not show light scattering.

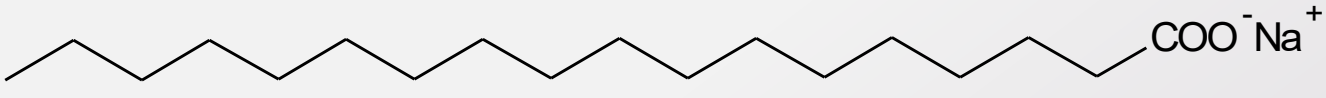


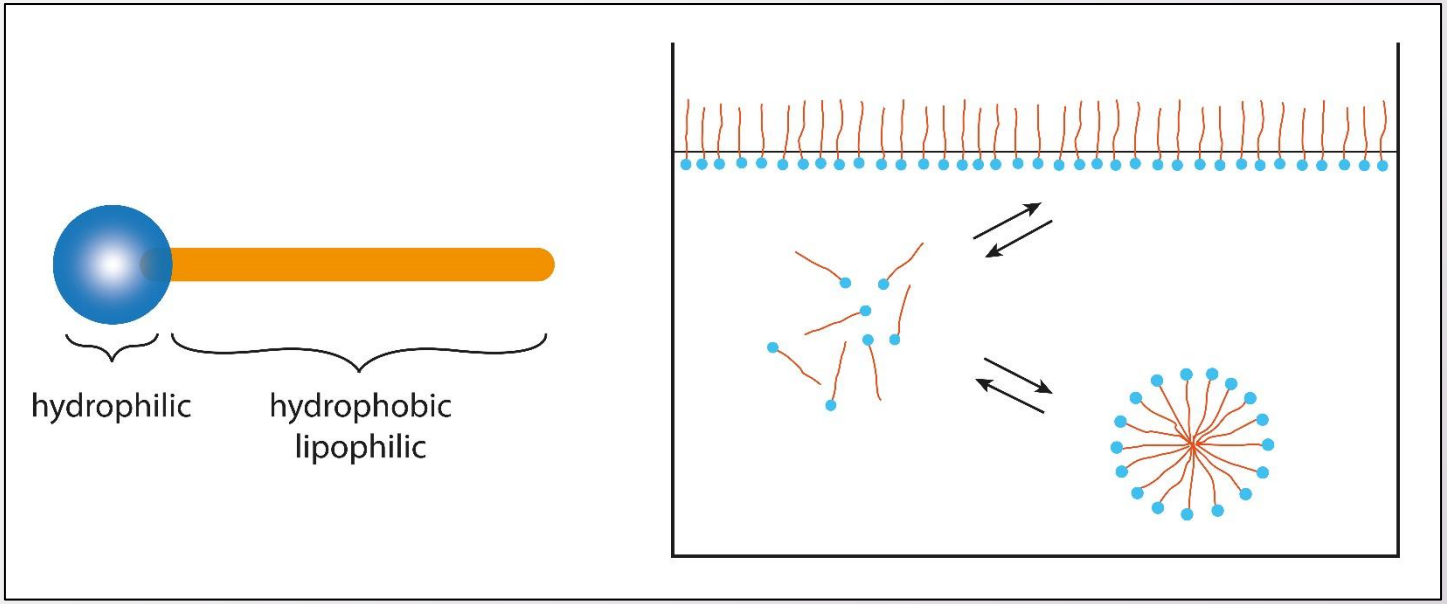
Shutterstock Image

- A good example of Tyndall effect is fog.
- Proteins also form colloids in water.
- Coagulation is a process when a colloid is aggregated (precipitated) e.g. curdled milk.

MICELLES

- These are formed when a molecule has both hydrophilic (water loving) and hydrophobic (water fearing) components.
- Classic example is soap.





Shutterstock Image

KEY CONCEPTS

- Solutions
- Raoult's Law
- Freezing point depression
- Boiling point elevation
- Osmosis
- Colloids