PROPERTIES OF SOLUTIONS
Chapter 13

13.4 Expressing Solution Concentration

13.5 Colligative Properties

Concentration Units

Solution:

homogeneous mixture of two or more components

Solute + Solvent → Solution

Concentration of solute:

either   Amount of solute/amount of solvent

or   Amount of solute/amount solution

Amount = moles, mass, or volume

Molarity (M)

Molarity: number of <u>moles</u> of solute per liter of <u>solution</u>.

$$M = \frac{\text{moles solute}}{\text{L solution}} \equiv \frac{\text{mol}}{\text{L}} \equiv \frac{\text{mmol}}{\text{mL}}$$

Number of mol = M x V (L)
Number of mol = M x V (mL)

Properties: T-dependent.

Molality (m)

Molality: number of <u>moles</u> of solute per kg of <u>solvent</u>.

$$m = \frac{\text{moles solute}}{\text{kg solvent}} \qquad M = \frac{\text{moles solute}}{\text{L solution}}$$

Number of mol = m x kg solvent

Properties: T-independent.

Mole Fraction (X)

$$X = \frac{\text{mol component}}{\text{total mol}}$$

$$X_i = \frac{n_i}{n_t}$$

Component A = 2 mol   Component B = 3 mol

$$X_A = \frac{2}{5} = 0.4 \qquad X_B = \frac{3}{5} = 0.6$$

$$X_1 + X_2 + X_3 + \ldots = 1 \qquad \text{T-independent}$$

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Mass Percent

$$\text{percent by mass} = \frac{\text{mass component}}{\text{mass solution}} \times 100\%$$

36% HCl solution by mass:

100 g solution ≡ 36 g HCl + 64 g H_2O

$$\text{mass}_1\% + \text{mass}_2\% + \ldots = 100$$

T-independent

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A sulfuric acid solution containing 571.6 g of H_2SO_4 per liter of solution has a density of 1.329 g/mL. Calculate (a) the mass percent; (b) the mole fraction; (c) the molality; (d) the molarity of H_2SO_4 in this solution.

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

mass solt = 571.6 g

$$\text{mass soln} = 1000.\ \text{mL} \times \frac{1.329\ \text{g}}{\text{mL}} = 1329\ \text{g}$$

$$\text{mass}\% = \frac{571.6\ \text{g}}{1329\ \text{g}} \times 100\% = 43.01\%$$

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$$X_{H_2SO_4} = \frac{\text{mol } H_2SO_4}{\text{mol } H_2SO_4 + \text{mol } H_2O}$$

$$n_{H_2SO_4} = 571.6\ \text{g } H_2SO_4 \times \frac{1\ \text{mol } H_2SO_4}{98.0\ \text{g } H_2SO_4}$$

$$n_{H_2SO_4} = 5.833\ \text{mol}$$

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Slide 9:

mass H_2O = mass of soln - mass of solt

mass H_2O = 1329 - 571.6 = 757.4 g H_2O

$$n_{H_2O} = 757.4 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O}$$

n_{H_2O} = 42.03 mol

$$X_{H_2SO_4} = \frac{5.833}{5.833 + 42.03} = 0.1219$$

$$X_{H_2O} = 1 - X_{H_2SO_4} = 1 - 0.1219 = 0.8781$$

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Slide 10:

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

$$m = \frac{5.833 \text{ mol } H_2SO_4}{0.7574 \text{ kg } H_2O} = 7.701 \ m$$

$$M = \frac{\text{moles solute}}{\text{L solution}}$$

$$M = \frac{5.833 \text{ mol}}{1 \text{ L}} = 5.833 \ M$$

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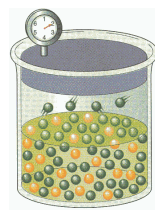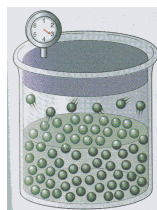
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Colligative Properties

H_2O H_2O + solt

	H_2O	H_2O + solt
Freezing Point	= 0°C	< 0°C
Boiling Point	= 100°C	> 100°C

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Slide 12:

Colligative Properties

Vapor Pressure Lowering ⬇

Boiling Point Elevation ⬆

Freezing Point Depression ⬇

Osmotic Pressure ⬆

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Colligative Properties

Properties that depend on the underline(concentration) (number) of solute underline(particles) in solution, not on the underline(nature) of the solute particles.

As the underline(concentration) of solute particles increases:

The vapor pressure	decreases ↓
The boiling point	increases ↑
The freezing point	decreases ↓
The osmotic pressure	increases ↑

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Colligative Properties

Conc.	# of particles	ΔT_b
1 m glucose	1	1.5°C
1 m urea	1	1.5°C
2 m glucose	1	3°C
1 m NaCl	2	3°C

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Vapor Pressure Lowering

- Adding a underline(nonvolatile) solute to a solvent underline(always) lowers the vapor pressure of the solvent.
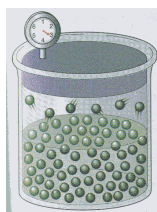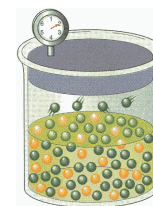
$P°_{solv}$ > P_{soln}
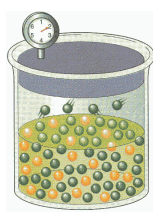
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Raoult's Law

The partial pressure of a solution is directly proportional to the mole fraction of the solvent in that solution.

$$P_1 = X_1 P°_1$$

$P°_1$ = vapor pressure of pure solvent

X_1 = mole fraction of the underline(solvent)

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Raoult's Law

$$P_1 = X_1 P°_1$$

If solution contains only one solute:

$$X_1 = 1 - X_2$$ X_2 = mole fraction of solute

$$P°_1 - P_1 = \Delta P = X_2 P°_1$$

The lowering in vapor pressure, ΔP, is directly proportional to the solute concentration, X_2.

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For two volatile liquids:

$$P_t = P_A + P_B$$

$$P_t = X_A P°_A + X_B P°_B$$

X_A: mole fraction of liquid A in liquid phase

X_B: mole fraction of liquid B in liquid phase

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What is the vapor pressure of a solution made by mixing 150.0 g glucose ($C_6H_{12}O_6$) with 600.0 g water at 25°C? (at 25°C the vapor pressure of pure water is 23.8 torr.)

$$P_1 = X_1 P°_1$$

$$150.0 \text{ g glu} \times \frac{1 \text{ mol}}{180.2 \text{ g glu}} = 0.8324 \text{ mol}$$

$$600.0 \text{ g } H_2O \times \frac{1 \text{ mol}}{18.02 \text{ g } H_2O} = 33.30 \text{ mol}$$

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$$X_{H_2O} = \frac{n_{H_2O}}{n_{H_2O} + n_{C_6H_{12}O_6}}$$

$$X_{H_2O} = \frac{33.30}{33.30 + 0.8324} = 0.9756$$

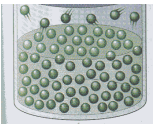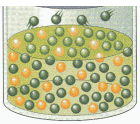$$P_1 = X_1 P°_1$$

$$P_1 = 0.9756 \times 23.8 = 23.2 \text{ mmHg}$$

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Boiling Point Elevation

A liquid boils when its vapor pressure equals the atmospheric pressure

solvent   **solution**

T_{H_2O}	100°C	100°C
P_{vapor}	1 atm	< 1 atm
	will boil	will not boil

to boil increase T >100°C

Boiling Point Elevation

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

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

T_b = boiling point of solution

T_b° = boiling point of pure solvent

K_b = molal boiling point elevation constant

m = molality of the solution

Boiling Point Elevation

$$K_b = \frac{\Delta T_b}{m} = \frac{°C}{m}$$

For water K_b = 0.52 °C/m

Each mole of solute particles <u>raises</u> the boiling point of 1 kilogram of water by 0.52 °C.

K_b: characteristic of solvent

Freezing Point Depression

$$\Delta T_f = K_f \cdot m$$

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

T_f = freezing point of solution

T_f° = freezing point of pure solvent

K_f = molal freezing point depression constant

m = molality of the solution

Freezing Point Depression

$$K_f = \frac{\Delta T_f}{m} = \frac{°C}{m}$$

For water $K_f = 1.86 \ °C/m$

Each mole of solute particles <u>lowers</u> the freezing point of 1 kilogram of water by 1.86°C.

K_f: characteristic of solvent

Molal Boiling Point Elevation and Freezing Point Depression Constants

Solvent	K_b	K_f (°C/m)
Water	0.52	1.86
Acetic Acid	3.7	3.90
Benzene	2.53	5.12
Phenol	3.56	7.27
Carbon Tetrachloride	4.02	29.8

List the following aqueous solutions in order of: (a) increasing freezing point; (b) increasing boiling point:

	<u>concentration of particles</u>	
1 m Ca(NO$_3$)$_2$	1 x 3	= 3 m
3 m KCl	3 x 2	= 6 m
4 m C$_6$H$_{12}$O$_6$	4 x 1	= 4 m
H$_2$O	0	= 0 m

(a) KCl < C$_6$H$_{12}$O$_6$ < Ca(NO$_3$)$_2$ < H$_2$O

(b) H$_2$O < Ca(NO$_3$)$_2$ < C$_6$H$_{12}$O$_6$ < KCl

What is the freezing point of a solution containing 478 g of ethylene glycol (C$_2$H$_6$O$_2$, antifreeze) in 3202 g of water?

$$\Delta T_f = K_f \cdot m \qquad K_f = 1.86 \ °C/m$$

$$m = \frac{mol \ solt}{kg \ solv} = \frac{478 \ g \times \dfrac{1 \ mol}{62.01 \ g}}{3.202 \ kg} = 2.41 \ m$$

$$\Delta T_f = K_f \cdot m \qquad\qquad K_f = 1.86 \ °C/m$$

$$\Delta T_f = \frac{1.86 \ °C}{m} \ x \ 2.41 \ m \ = 4.48 \ °C$$

$$\Delta T_f = T_f° - T_f$$

$$T_f = T_f° - \Delta T_f$$

$$T_f = 0.00 \ °C - 4.48°C = - 4.48 \ °C$$

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What volume of ethyleneglycol ($C_2H_6O_2$) must be added to 15.0 L of water to produce an antifreeze solution with a freezing point of -30.0°C? What is the boiling point of this solution? Density of $C_2H_6O_2$ = 1.11 g/mL and for water 1.00 g/mL.

$$\Delta T_f = T_f° - T_f \ = 0.00 \ °C - \ (- 30.0 \ °C) = 30.0 \ °C$$

$$\Delta T_f = K_f \cdot m$$

$$30.0 = 1.86 \ °C/m \ x \ m$$

$$m = 16.13 \ m \ = 16.13 \ \frac{mol \ eg}{Kg \ H_2O}$$

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$$\frac{16.13 \ mol \ eg}{kg \ H_2O} x \ 15 \ kg \ H_2O \ = 242 \ mol \ eg$$

$$242 \ mol \ eg \ x \ \frac{62.01 \ g \ eg}{1 \ mol \ eg} = 15006 \ g \ eg$$

$$15006 \ g \ eg \ x \ \frac{1 \ mL}{1.11 \ g \ eg} x \ \frac{1 \ L}{1000 \ mL}$$

$$= 13.5 \ L$$

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Osmotic Pressure

Osmosis:

Flow of solvent molecules through a semipermeable membrane from a dilute solution to a more concentrated one
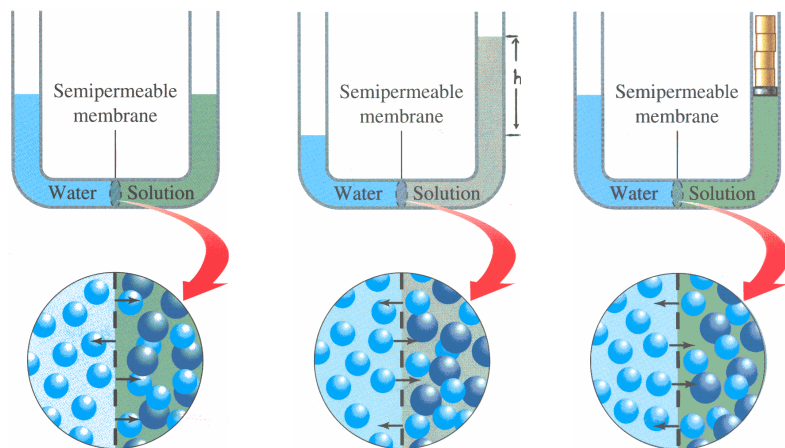
semipermeable membrane:

Allows the passage of solvent molecules but not the solute molecules

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Osmosis

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Osmotic Pressure:

The minimum pressure that stops osmosis.

$\pi = MRT$ π = osmotic pressure in atm

M = molarity of solution

R = gas constant

T = temperature in K

$\pi_1 = \pi_2$ isotonic solutions

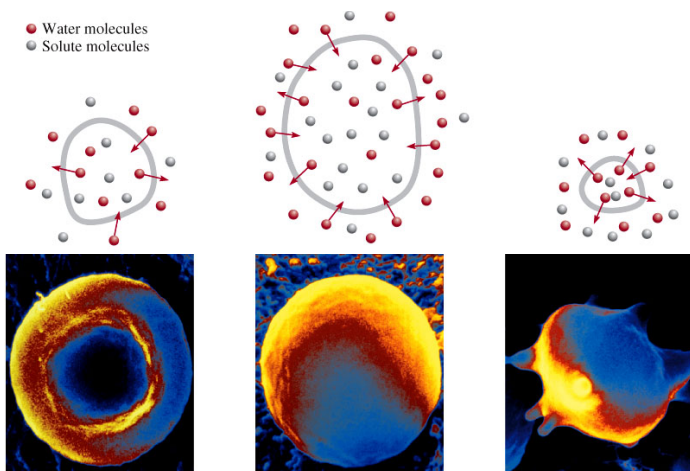$\pi_1 > \pi_2$ soln$_1$: hypertonic   concentrated

soln$_2$: hypotonic   diluted

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A cell in an:

isotonic solution   *hypotonic* solution   *hypertonic* solution

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Determination of Molar Mass

Any of the colligative properties can be used for molar mass determination of the solute with osmotic pressure being the most accurate.

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A 20.0 mg sample of a protein is dissolved in 25.0 mL of solution. The osmotic pressure of the solution is 0.56 torr at 25°C. What is the molar mass of the protein?

$$M = \frac{\pi}{RT} = \frac{0.56 \text{ torr} \times \dfrac{1 \text{ atm}}{760 \text{ torr}}}{0.0821 \dfrac{L.atm}{mol.K} \times 298 \text{ K}}$$

$$M = 3.01 \times 10^{-5} \ M$$

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$$3.01 \times 10^{-5} \ \frac{mol}{L} \ \text{x} \ \frac{25.0 \text{ mL} \ \text{x} \ 1 \text{ L}}{1000 \text{ mL}}$$

$$= 7.5 \times 10^{-7} \ mol$$

$$\mathcal{M} = \frac{20.0 \text{ mg} \ \text{x} \ \dfrac{1 \text{ g}}{1000 \text{ mg}}}{7.5 \times 10^{-7} \ mol} = 2.67 \times 10^4 \ g/mol$$

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When 0.186 g of an organic substance is dissolved in 22.01 g of liquid camphor ($C_{10}H_{16}O$), the freezing point of the solution is found to be 176.7°C. What is the molar mass of the organic compound?

For camphor: $T°_f = 179.8 \ °C$, $K_f = 40.0°C/m$

$$\Delta T_f = K_f \ m$$

$$\Delta T_f = T°_f - T_f \ = 179.8 - 176.7 \ = 3.1°C$$

$$3.1°C = \ 40.0°C/m \ \text{x} \ m$$

$$m = 0.0775 \ m$$

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$$\frac{0.0775 \text{ mol solt}}{kg \text{ solv}} \ \text{x} \ 0.02201 \text{ kg solv}$$

$$= 1.71 \times 10^{-3} \ mol$$

$$\mathcal{M} = \frac{g}{mol} = \frac{0.186 \text{ g}}{1.71 \times 10^{-3} \ mol} = 109 \ g/mol$$

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