

Outline

- Solutions and Solubility
- Concentration Units
- Colligative Properties of Solutions

Solutions and Solubility

Solution	A homogeneous mixture
Solvent	The major component of the solution
Solute	The minor component(s) of a solution

Solubility describes amount of solute that will dissolve in a solvent

Substances with intermolecular forces of similar type and magnitude will be soluble in one another (“like dissolves like”)

Nonpolar solvent, Nonpolar solute

Solvent-solute LDFs are as strong as the solvent-solvent or solute-solute LDFs

Nonpolar solvent, Polar solute

Solvent-solute LDFs are too weak to overcome the solute-solute dipole-dipole attractions

Polar Solvent, Nonpolar Solute

Same result as given before...

Polar Solvent, Polar Solute

Solvent-solute dipole-dipole attractions are as strong as solvent-solvent or solute-solute dipole-dipole attractions

H-Bonding Solvent, Polar Solute

The solute will only dissolve in the solvent if H-Bonds can be formed between the solvent and solute

Solvent	Solute	Solubility – High or Low?
C_6H_6	C_8H_{18}	High
C_6H_6	CH_2Br_2	Low
CH_2Cl_2	C_8H_{18}	Low
CH_2Cl_2	CH_2Br_2	High
H_2O	C_8H_{18}	Low
H_2O	CH_2Cl_2	Low (a little)
H_2O	CH_3OH	High

When polar molecules dissolve into water, they remain intact and are surrounded by water molecules

Solute molecules surrounded by water molecules are said to be hydrated

The polar liquid water dissolves ionic substances because the water and ion form ion-dipole attractions

These attractions are strong enough to separate the positive and negative ions from each other in the crystal

The separation of ions from an ionic crystal during the dissolving process is called dissociation

The Dissolving Process:

1. Separating ions from each other

Must overcome the lattice energy; endothermic

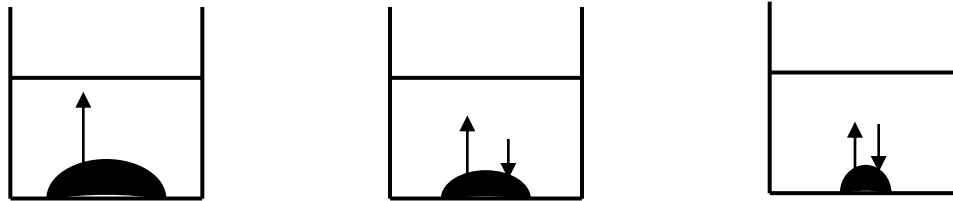
2. Attracting water molecules to the free ions

The attraction is the hydration energy; exothermic

If lattice energy $>$ hydration energy, the dissolving is endothermic

If hydration energy $<$ lattice energy, the dissolving is exothermic

When the maximum amount of solute has dissolved in a given amount of solvent, the solute is saturated



A saturated solution is in solution equilibrium, the rates of dissolving and crystallizing are equal

If the solute concentration is...

less than saturated, then unsaturated

more than saturated, then supersaturated

Solubility may also be affected by...

Temperature

Increasing temperature generally increases the solid's solubility

Increasing the temperature decreases gas solubility

Pressure

Increasing the pressure increases the gas solubility

Henry's Law

The amount of a gas dissolved in a liquid is directly proportional to the gas' pressure above the liquid

$$C_{\text{gas}} = k_{\text{H}} P_{\text{gas}} \quad (C = \text{concentration and } k_{\text{H}} = \text{constant})$$

Concentration Units

Concentration is the amount of solute dissolved in a given quantity of solvent or solution

1. Mass Percent (%)

Grams of solute per grams of solution (x 100)

2. Molarity (M)

Moles of solute per liter of solution

3. Molality (m)

Moles of solute per kilogram of solvent

What is the molarity of a 1.56%(m/m) of sodium chloride, density equal to 1.08 g/mL?

$$\frac{1.56 \text{ g NaCl}}{100 \text{ g soln}} \times \frac{1 \text{ mol}}{58.44 \text{ g}} \times \frac{1.08 \text{ g}}{1 \text{ mL}} \times \frac{1 \text{ mL}}{1 \times 10^{-3} \text{ L}} = \underline{0.288 \text{ M NaCl}}$$

What is the molality if 11.8 g of glucose, $\text{C}_6\text{H}_{12}\text{O}_6$ ($M = 180.16$ g/mol) are dissolved in 150. g of water?

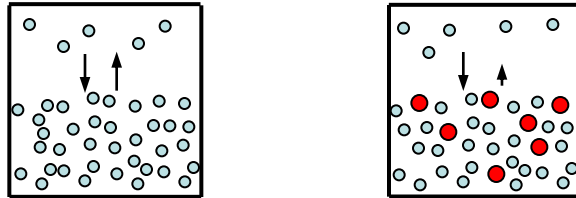
$$11.8 \text{ g C}_6\text{H}_{12}\text{O}_6 \times \frac{1 \text{ mol}}{180.16 \text{ g}} = 0.065497 \text{ mol C}_6\text{H}_{12}\text{O}_6$$

$$? \text{ m} = \frac{\text{moles solute}}{\text{kg solvent}} = \frac{0.065497 \text{ mol C}_6\text{H}_{12}\text{O}_6}{0.150 \text{ kg water}} = 0.43664 \text{ m} = \underline{0.437 \text{ m}}$$

Colligative Properties of Solutions

Colligative properties are those that depend only on the number of solute particles, not their identity...

1. Vapor Pressure Lowering



With solute particles taking spots on the surface, the rate of vaporizing is less than the rate of condensing

To equalize the rates, the number of vapor molecules must be decreased; the remaining vapor molecules exert a lower pressure

If a solution's solute does not evaporate, the solute is nonvolatile

Raoult's Law

The equilibrium vapor pressure of a solution equals the mole fraction of the solvent times the equilibrium vapor pressure of the pure solvent

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

P_{solution}	vapor pressure of the solution
χ_{solvent}	mole fraction of solvent
$P^{\circ}_{\text{solvent}}$	vapor pressure of the pure solvent

$$P = \chi P^{\circ}$$

The vapor pressure of water at 20 °C is 17.5 torr. If 158 g of sucrose (MM = 342 g/mol) is dissolved in 642 g of water, what will be the vapor pressure of the solution?

158 g sucrose \Rightarrow 0.462 mol sucrose

642 g H₂O \Rightarrow 35.7 mol H₂O

$$\chi_{\text{H}_2\text{O}} = \frac{35.7 \text{ mol H}_2\text{O}}{0.462 \text{ mol} + 35.7 \text{ mol}} = 0.987$$

$$P = \chi P^\circ = (0.987)(17.5 \text{ torr}) = \underline{17.3 \text{ torr}}$$

If a solute is an electrolyte (a salt or an acid), its ionization must be considered

Water vapor pressure is 17.5 torr at 20 °C. If 35.0 g Na₂SO₄ (MM = 142 g/mol) is dissolved in 175 g H₂O, what will be the vapor pressure of the solution?

$$35.0 \text{ g Na}_2\text{SO}_4 \Rightarrow 0.246 \text{ mol Na}_2\text{SO}_4$$

$$175 \text{ g H}_2\text{O} \Rightarrow 9.71 \text{ mol H}_2\text{O}$$

$$n_{\text{solute}} = 3 \times 0.246 \text{ mol} = 0.738 \text{ mol solute}$$

$$\chi_{\text{H}_2\text{O}} = \frac{9.71 \text{ mol}}{0.738 \text{ mol} + 9.71 \text{ mol}} = 0.929$$

$$P = \chi P^\circ = (0.929)(17.5 \text{ torr}) = \underline{16.3 \text{ torr}}$$

Colligative properties can be used to calculate the molar mass of a nonvolatile solute

If a solution's solute does evaporate, the solute is volatile

If solvent and the solute are volatile, the vapor pressure of the solution is...

$$P = P_{\text{solvent}} + P_{\text{solute}}$$

$$P = P_A + P_B$$

$$P = \chi_A P_A^{\circ} + \chi_B P_B^{\circ}$$

A solution is 17.4 g acetone (MM = 58.0 g/mol) and 11.9 g chloroform (MM = 119 g/mol). Find the solution's vapor pressure if the vapor pressure of acetone is 345 torr and that of chloroform is 293 torr.

17.4 g acetone \Rightarrow 0.300 mol acetone

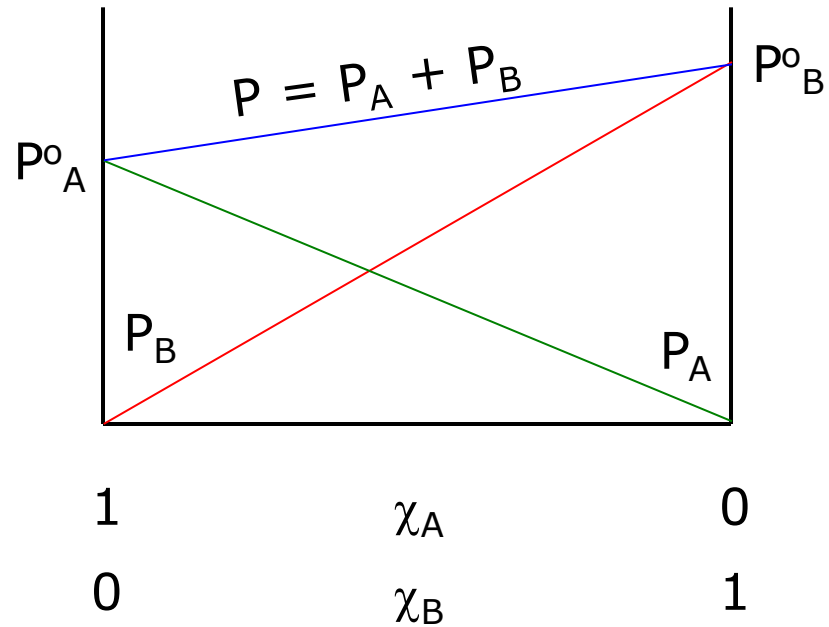
11.9 g chloroform \Rightarrow 0.100 mol chloroform

$$P = \chi_A P_A^{\circ} + \chi_B P_B^{\circ}$$

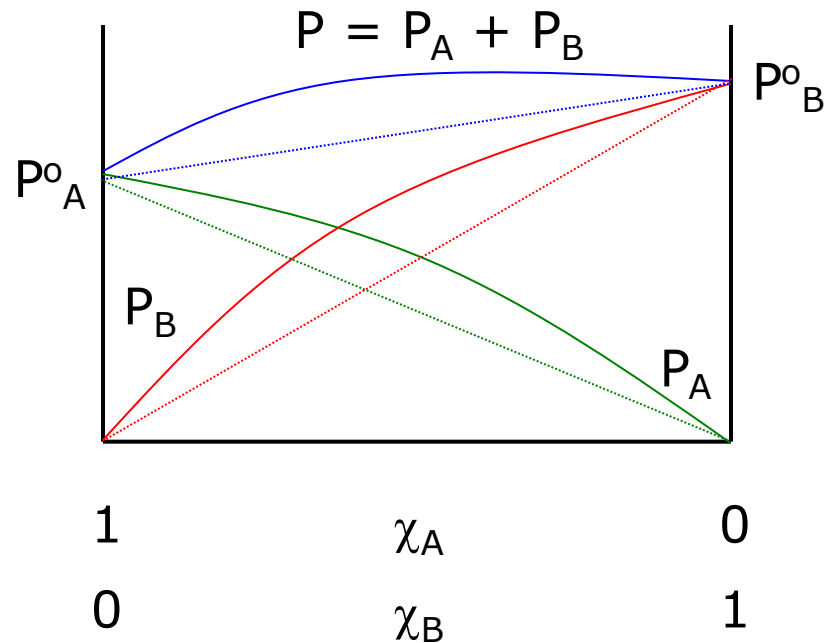
$$P = \left(\frac{0.300 \text{ mol}}{0.400 \text{ mol}} \right) (345 \text{ torr}) + \left(\frac{0.100 \text{ mol}}{0.400 \text{ mol}} \right) (293 \text{ torr})$$

$$P = 259 \text{ torr} + 73.2 \text{ torr} = \underline{332 \text{ torr}}$$

Any solution obeying Raoult's Law is termed an ideal solution

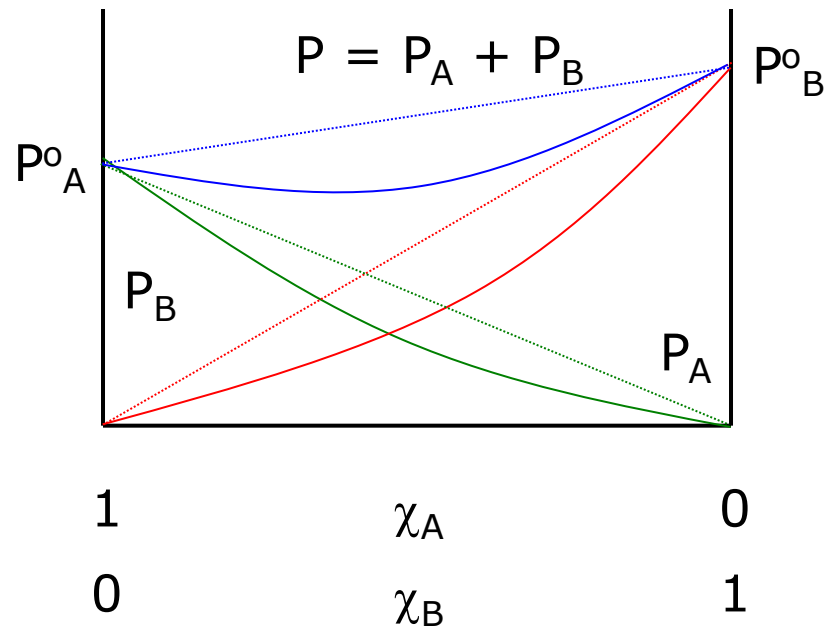


Positive deviation occurs when the solvent-solute attractions are weaker than solvent-solvent or solute-solute attractions



These solutions have $\Delta H_{\text{solution}} = +$

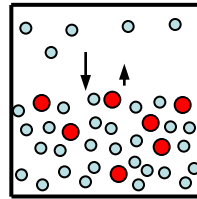
Negative deviation occurs when the solvent-solute attractions are very strong (e.g., solvent-solute hydrogen bonds)



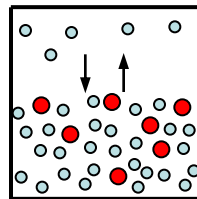
These solutions have $\Delta H_{\text{solution}} = -$

2. Boiling Point Elevation

With solute particles, the vapor pressure is less than atmospheric pressure



To equalize the pressures, the vapor pressure must be raised by increasing the temperature



$$\Delta T_B = K_B m i$$

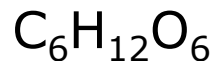
ΔT_B = increase in boiling point

K_B = molal boiling point constant

m = molality of solution

i = van't Hoff factor

= $\frac{\text{moles of particles in solution}}{\text{moles of solute dissolved}}$



1



2



2



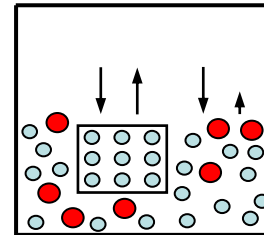
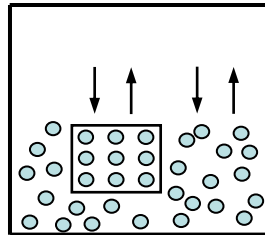
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If pure water boils at 100.00 °C and has a molal boiling point constant of 0.514 °C/m, what is the boiling point of a solution 1.90 m in NaCl?

$$\Delta T_B = K_B m i = (0.514 \text{ }^\circ\text{C/m})(1.90 \text{ m})(2) = 1.95 \text{ }^\circ\text{C}$$

$$T_B = 100.00 \text{ }^\circ\text{C} + 1.95 \text{ }^\circ\text{C} = \underline{101.95 \text{ }^\circ\text{C}}$$

3. Freezing Point Depression



With solute particles, the vapor pressure of the liquid is less than the vapor pressure of the solid

To equalize vapor pressures and reach equilibrium, the temperature must be lowered

$$\Delta T_F = K_F m_i$$

ΔT_F = decrease in freezing point

K_F = molal freezing point constant

Find the freezing point of a water solution that is 3.00% sodium chloride by mass. The molal freezing point constant for water is 1.86 °C/m.

3.00% is 3.00 g NaCl for 100 g of solution...

100 g solution is 3.00 g NaCl and 97.00 g H₂O...

3.00 g NaCl \Rightarrow 0.0513 mol NaCl

$$\frac{0.0513 \text{ mol NaCl}}{0.09700 \text{ kg H}_2\text{O}} = 0.529 \text{ m}$$

$$\Delta T_F = K_F m i = (1.86 \text{ }^\circ\text{C/m})(0.529 \text{ m})(2) = 1.97 \text{ }^\circ\text{C}$$

$$T_F = 0.00 \text{ }^\circ\text{C} - 1.97 \text{ }^\circ\text{C} = \underline{-1.97 \text{ }^\circ\text{C}}$$

4. Osmotic Pressure

Movement of solvent from dilute solution to concentrated solution is osmosis



Semipermeable membranes allow solvent molecules to pass but not solute molecules, e.g. water does pass but salt ions do not

Pressure required to stop osmosis is osmotic pressure (Π)

$$\Pi = iMRT$$

Π = osmotic pressure (atm)

M = molarity

R = 0.08206 L atm/mol K

T = temperature (K)

i = van't Hoff factor

5.00 g glucose (MM 180. g/mol) are dissolved in water to make 100. mL of solution. The solution is placed in contact with pure water through a semipermeable membrane. What osmotic pressure develops at 22 °C?

5.00 g glucose \Rightarrow 0.0278 mol glucose

$$\frac{0.0278 \text{ mol}}{0.100 \text{ L}} = 0.278 \text{ M}$$

$$\Pi = iMRT = (1)(0.278 \text{ M})(0.08206 \text{ L atm/mol K})(295 \text{ K})$$

$$\Pi = \underline{6.73 \text{ atm}}$$