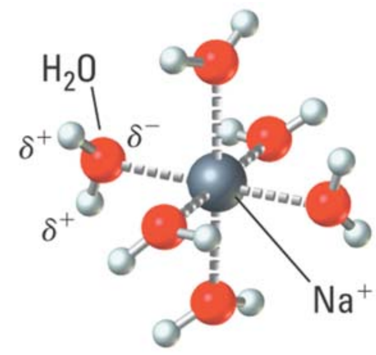
Solutes and Solution

- The first rule of solubility is "likes dissolve likes"
- Polar or ionic substances are soluble in polar solvents
- Non-polar substances are soluble in non-polar solvents

Saturation and Equilibrium



Solutes and Solution

- There must be a reason why a substance is soluble in a solvent:
  - either the solution process lowers the overall enthalpy of the system ($\Delta H_{rxn} < 0$)
  - Or the solution process increases the overall entropy of the system ($\Delta S_{rxn} > 0$)
- Entropy is a measure of the amount of disorder in a system—entropy must increase for any spontaneous change

Solutes and Solution

- The forces that drive the dissolution of a solute usually involve both enthalpy and entropy terms
  - $\Delta H_{soln} < 0$ for most species
  - The creation of a solution takes a more ordered system (solid phase or pure liquid phase) and makes more disordered system (solute molecules are more randomly distributed throughout the solution)

Saturation and Equilibrium

- If we have enough solute available, a solution can become saturated—the point when no more solute may be accepted into the solvent
- Saturation indicates an equilibrium between the pure solute and solvent and the solution

  solute + solvent ↔ solution K_C

Saturation and Equilibrium

solute + solvent ↔ solution K_C

- The magnitude of K_C indicates how soluble a solute is in that particular solvent
- If K_C is large, the solute is very soluble
- If K_C is small, the solute is only slightly soluble

Saturation and Equilibrium

<u>Examples:</u>

$NaCl(s) + H_2O(\ell) \leftrightarrow Na^+(aq) + Cl^-(aq)$

$K_C = 37.3$

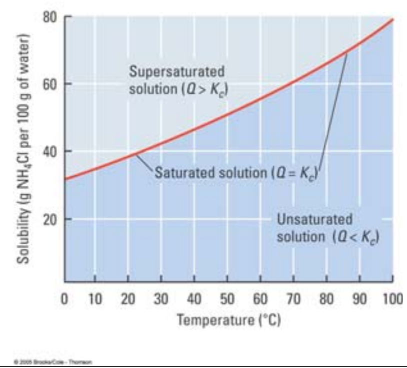
A saturated solution of NaCl has a $[Na^+]$ = 6.11 M and $[Cl^-]$ = 6.11 M

$AgCl(s) + H_2O(\ell) \leftrightarrow Ag^+(aq) + Cl^-(aq)$

$K_C = 1.8 \times 10^{-10}$

A saturated solution of AgCl has a $[Ag^+]$ = 1.34×10^{-5} M and $[Cl^-]$ 1.34×10^{-5} M

Saturation and Equilibrium



Colligative Properties

- Colligative properties are a set properties that depend only on the amount of solute in a solution, and not on the chemical identity of the solute
- Colligative properties include:
  - Vapor pressure lowering
  - Freezing point depression
  - Boiling point elevation
  - Osmotic pressure

Colligative Properties

Vapor pressure lowering

- When solute is added to a pure solvent, solvent molecules are "tied up" in keeping the solute molecules in solution
- Because solvent molecules are more strongly attracted to the solute than to themselves, it requires more energy to remove them from the solution compared to the pure solvent

Colligative Properties

Vapor pressure lowering

- As a consequence, the vapor pressure of the solution is lowered
- Raoult's Law states:

  $P_1 = X_1 P_1^o$

  P_1 = vapor pressure of the solution

  X_1 = mole fraction of solvent

  P_1^o = vapor pressure of the pure solvent

Colligative Properties

Vapor pressure lowering

Example: What is the vapor pressure of a saturated NaCl solution at 25 ^oC?

P^o = 23.76 Torr

ρ_{H2O} = 0.99707 g/mL

35.7 g NaCl per 100 mL H_2O

Step 1—Determine mole fraction of solution

35.7 g NaCl/58.443 g/mol =0.611 mol NaCl

(100 mL)(.9971 g/mL)/(18.0152 g.mol) =5.53 mol H_2O

Colligative Properties

Vapor pressure lowering

Example: What is the vapor pressure of a saturated NaCl solution at 25 °C?

Step 1—Determine mole fraction of solution

$$X = \frac{5.53 \text{ mol}}{2(.611 \text{ mol}) + 5.53 \text{ mol}} = .819$$

Colligative Properties

Vapor pressure lowering

Example: What is the vapor pressure of a saturated NaCl solution at 25 °C?

Step 2—Determine vapor pressure of solution

$$P = X P^{o} = (.819)(23.76 \text{ Torr})$$
$$= 19.5 \text{ Torr}$$

The vapor pressure over a saturated NaCl solution is nearly 20% lower than that of pure water

Colligative Properties

Boiling Point Elevation

- Because the vapor pressure of solution is lower than the vapor pressure of the pure solvent, the solution's boiling point will be elevated
- Remember that the boiling point is that temperature where the vapor pressure of the solution is equal to the pressure over the solution

Colligative Properties

Boiling Point Elevation

$\Delta T_b = T_b(\text{soln}) - T_b(\text{solvent})$

$= K_b\, m$

K_b = boiling point elevation constant

m = molality of solute

Colligative Properties

Boiling Point Elevation

Example: What is boiling point of a NaCl solution that is saturated at 25 °C?

$K_b(H_2O)$ = 0.512 K kg/mol

m = (1.22 mol solute)/(.09771 kg H_2O)

= 12.5 m

ΔT_b = (12.5 mol/kg)(0.512 K kg/mol) = 6.40 K

T_b = 106.4 °C

Colligative Properties

Freezing Point Depression

- The freezing point of a solution will be lower than that of the pure solvent because the solute molecules interrupt the crystal structure of the solid solvent

$\Delta T_f = K_f\, m$

K_f = freezing pt depression constant

m = molality of solute

Colligative Properties

Freezing Point Depression

Example: Determine the freezing point of a solution that is 40% by volume ethylene glycol in water

$K_f(H_2O)$ = 1.86 K kg/mol

$\rho(C_2H_6O_2)$ =1.109 g/mL

Colligative Properties

Freezing Point Depression

Example: Determine the freezing point of a solution that is 40% by volume ethylene glycol in water

Step 1—Assume we have 1.00 L of the solution; determine molality of ethylene glycol

(400 mL $C_2H_6O_2$)(1.109 g/mL)/(62.069 g/mol)

= 7.15 mol $C_2H_6O_2$

m = (7.15 mol)/(.600 kg H_2O) =11.9 m

Colligative Properties

Freezing Point Depression

Example: Determine the freezing point of a solution that is 40% by volume ethylene glycol in water

Step 2—Determine freezing point depression

ΔT_f = (11.9 m)(1.86 K kg/mol)

= 22.1 K

T_f = -22.1 ^oC