Chemistry: The Central Science

Chapter 13: Properties of Solutions

- Homogeneous mixture is called a solution
  - Can be solid, liquid, or gas
- Each of the substances in a solution is called a component of the solution
  - Solvent is normally the component present in greatest amount
  - Other components are solutes
- Liquid solutions are most common

13.1: The Solution Process

- A solution is formed when one substance disperses uniformly throughout another
- The ability of substances to form solutions depends on two general factors
  - The type of intermolecular interactions involved in the solution process
  - The natural tendency of substances to spread into larger volumes when not restrained in some way
- The Effect of Intermolecular Forces
  - Intermolecular forces can operate between solute and solvent particles in a solution
    - Solutions form when the magnitude of attraction between solute and solvent is greater than the attraction between solute particles or between solvent particles
    - E.g. NaCl dissolving in water
      - The attraction between Na\(^+\) and Cl\(^-\) is less than the attraction of the ions to the water molecules
      - Ion-dipole forces
        - The Na\(^+\) is attracted to the O (δ\(^-\)) atom of the water molecule
        - The Cl\(^-\) is attracted to the H (δ\(^+\)) atom of the water molecule
          - Causing the water to form a sphere around the ions
      - Such interaction between solute and solvent molecules are called salvation
        - If water is the solvent, the interactions are referred to as hydration
- Energy Changes and Solution Formation
  - Overall enthalpy change in forming a solution is \(\Delta H_{\text{soln}}\)
    - \(\Delta H_{\text{soln}} = \Delta H_1 + \Delta H_2 + \Delta H_3\)
      - \(\Delta H_1\) is the separation of solute thus it is endothermic
        - \(\Delta H_1 > 0\)
      - \(\Delta H_2\) is the separation of solvent which is also endothermic
• $\Delta H_2 > 0$
  - $\Delta H_3$ is the attraction between solute and solvent and is exothermic
    - $\Delta H_3 < 0$
• Formation of solution can be either endothermic or exothermic
• If $\Delta H_{\text{soln}}$ is too endothermic, a solution will not form
  - The solvent-solute interaction must be strong enough for $\Delta H_3$ to be comparable in magnitude with $\Delta H_1 + \Delta H_2$
  - E.g. NaCl in gasoline
    - The attraction between gasoline and NaCl is not strong enough to overcome the cohesive force between NaCl and between gasoline
• Solution Formation, Spontaneity, and Entropy
  - Processes that occur spontaneously involve two distinct factors
    - Energy and distribution of each component
  - Processes in which the energy content of the system decreases tend to occur spontaneously (exothermic)
    - Some spontaneous processes are endothermic, however
  - Formation of a homogeneous solution increases the degree of dispersal, or randomness, because the molecules of each substance are now distributed in a volume twice as large
    - The degree of randomness in the system is called entropy
    - Processes occurring at a constant temperature in which the randomness or dispersal in space (entropy) of the system increases tend to occur spontaneously
  - Solution process involves two factors:
    - Change in enthalpy
    - Change in entropy
  - In general, the formation of solutions is favored by the increase in entropy that accompanies mixing
• Solution Formation and Chemical Reactions
  - Solution formation and chemical reactions are not same
  - When reacts, drying the product solution would not give the reactants
  - For solution formation, the substance can be recovered from the solution by evaporating the solution to dryness

13.2: Saturated Solutions and Solubility
• When solute dissolve in solvent, the concentration of solute particles increases
This increase the chances of the solute particle colliding with the surface of the solid thus could become reattached to the solid
  - This process is called crystallization
  - Opposite of dissolve
- Solubility is the maximum amount of solute that will dissolve in a given amount of solvent at a specified temperature, given that excess solute is present
  - A solution that is in equilibrium with undissolved solute is saturated
    - Additional solute will not dissolve if added
  - A solution with lower amount of solute than to form a saturated solution is unsaturated
    - Additional solute can dissolve
  - Under suitable conditions it is sometime possible to make a supersaturated solution
    - Possibly form from making a saturated solution at high temperature then lower the temperature
    - Is unstable
    - For crystallization to occur, the molecules or ions of solute must arrange themselves properly to form crystal

13.3: Factors Affecting Solubility
- The extent to which one substance dissolves in another depends on the nature of both solute and solvent
  - Also depends on temperature and, for gas, pressure
- Solute-Solvent Interactions
  - The solubility of gas in water increase with increasing molecular mass or polarity
    - The attractive forces between the gas and solvent molecules are mainly London dispersion type, which increases with increasing size and mass of the gas molecules
  - The stronger the attractions are between solute and solvent molecules, the greater the solubility
  - Pairs of liquids that dissolve in one another is miscible, where as those that do not are immiscible
  - Alcohols have OH group which is polar while the C—C is nonpolar and C—H is nearly nonpolar
    - The longer the C—C chain in alcohol with one OH, the less significant is the polarity of the OH thus is less soluble in polar solvent and more soluble in nonpolar solvent
Increasing the number of polar groups a molecule contain increases the extent of solubility in water (polar solvent)

Substances with similar intermolecular attractive forces tend to be soluble in one another a.k.a. like dissolves like

- Pressure Effects
  - The effect of pressure on solids and liquids is not appreciable
  - Affect the solubility of a gas
  - The solubility of the gas increases in direct proportion to its partial pressure above the solution
    - When pressure above the solution increase, volume decrease thus the pressure of the gas also increase
      - The rate in which the molecules strike the surface to enter the solution would therefore increase
    - Can be calculate using Henry’s law
      - \( S_g = kP_g \)
        - \( S_g \) is the solubility of the gas in the solution phase
        - \( P_g \) is the partial pressure of the gas over the solution
        - \( K \) is a proportionality constant known as Henry’s law constant
          - Different for each solute-solvent pair
          - Also varies with temperature

- Temperature Effects
  - The solubility of most solid solutes in water increases as temperature of the solution increases
    - There are still exceptions such as \( \text{Ce}_2(\text{SO}_4)_3 \)
  - The solubility of gases in water decreases with increasing temperature
    - The decrease solubility of \( \text{O}_2 \) in water as temperature increases is one of the effects of thermal pollution of lakes and streams

13.4: Ways of Expressing Concentration

- Concentration can be express in either qualitatively or quantitatively
  - Qualitatively – dilute and concentrated
  - Quantitatively – mass percentage, mole fraction, molarity, and molality

- Mass Percentage, ppm, and ppb
  - Mass percentage is the amount of component of solution per hundred
    - \( \text{Mass } \% \) of component = \( \frac{\text{mass of component in soln}}{\text{total mass of soln}} \times 100 \)
A solution of hydrochloric acid that is 36% HCl by mass contain 36 g of HCl for every 100 g of solution

- Often express concentrations of very dilute solution in parts per million (ppm) or parts per billion (ppb)
  - ppm of component = \( \frac{\text{mass of component in soln}}{\text{total mass of soln}} \times 10^6 \)
  - A solution whose concentration is 1 ppm contains 1 g of solute for each million \((10^6)\) grams of solution or, equivalently, 1 mg of solute per kilogram of solution

- **Mole Fraction, Molarity, and Molality**
  - **Mole fraction**
    - Mole fraction of component = \( \frac{\text{moles of component}}{\text{total moles of all components}} \)
    - Mole fractions have no units because they cancel out
    - Often use \( X \) for mole fraction
      - E.g. \( X_{\text{HCl}} \)
    - The sum of the mole fractions of all components of a solution must equal to 1
  - **Molarity** is moles of solute per liters of solution
    - Molarity = \( \frac{\text{moles solute}}{\text{liters soln}} \)
  - **Molality of a solution**, denoted, \( m \), is the number of moles of solute per kilogram of solvent
    - Molality = \( \frac{\text{moles of solute}}{\text{kilograms of solvent}} \)
  - Molarity and molality is often confused
    - Molarity depends on volume of solution
    - Molality depends on mass of solvent
    - When water is the solvent, the molality and molarity of dilute solutions are about the same

- **Conversion of Concentration Units**
  - To interconvert molality and molarity, the density of the solution is needed

### 13.5: Colligative Properties

- Solutions have lower freezing point and higher boiling point than pure solvent
  - Does not depend of the kind or identity of the solute particles
- Properties that only depends on the quantity of the solute (concentration) is called colligative properties
- Lowering the Vapor Pressure
A substance that has no measureable vapor pressure is nonvolatile, whereas one that exhibits a vapor pressure is volatile.

- Adding nonvolatile solute to a solvent always lowers the vapor pressure.

The extent to which a nonvolatile solute lowers the vapor pressure is proportional to its concentration.

- Express by Raoult’s law
  
  \[ P_A = X_A P_A^0 \]

  - \( P_A \) is the solvent vapor pressure above solution.
  - \( X_A \) is the mole fraction of the solvent.
  - \( P_A^0 \) is the pressure of pure solvent.
  - Ideal solution obeys Raoult’s law.

- Some solutions do not obey Raoult’s law
  
  - Real solutions best approximate ideal behavior when the solute concentration is low and when the solute and solvent have similar molecular sizes and similar types of intermolecular attractions.
  - If the intermolecular forces between solvent and solute are weaker than between solute-solute and solvent-solvent, the vapor pressure tend to be greater than predicted.
  - When interactions between solute and solvent are exceptionally strong, the vapor pressure is lower than predicted.

- Boiling-Point Elevation
  
  - The boiling point of the solution is higher than that of the pure liquid.
  - The increase in boiling point relative to that of the pure solvent, \( \Delta T_b \), is directly proportional to the concentration of the solution expressed by its molality, \( m \).
    
    \[ \Delta T_b = K_b m \]

    - The magnitude of \( K_b \), which is called the molal boiling-point-elevation constants, depends only on the solvent.
  - It’s also important to know whether the solute is an electrolyte or a nonelectrolyte.
    
    - Different solutes could give off different number of particles.

- Freezing-Point Depression
  
  - Because the triple-point temperature of the solution is lower than that of the pure liquid, the freezing point of the solution is lower than that of the pure liquid.
- \( \Delta T_f = K_f m \)
- \( K_f \) is the molal freezing-point-depression constant

- **Osmosis**
  - The net movement of solvent is always toward the solution with the higher solute concentration
    - The process is called osmosis
  - When liquid is put in a u-shape tube with semipermeable membrane in the middle, and one side has higher concentration of solute than the other
    - Osmosis would occur until the pressure difference between the water level of the two side are so large that the net flow of solvent ceases
      - The pressure required to prevent osmosis by pure solvent is the osmotic pressure (\( \Pi \))
        - \( \Pi = \left( \frac{n}{V} \right) RT = MRT \)
        - \( M \) is the molarity of the solution
  - If two solutions of identical osmotic pressure are separated by a semipermeable membrane, no osmosis will occur
    - The two solutions are isotonic
  - If one solution is of lower osmotic pressure, it’s hypotonic with respect to the more concentrated solution
    - The more concentrated solution is hypertonic with respected to the dilute solution
  - Osmosis plays a very important role in living systems
    - E.g. Swelling and bursting (Hymolysis) as well as shrinking (Crenation) of red blood cell

- **Determination of Molar Mass**
  - Provide a useful means of experimentally determining molar mass
    - From molality and etc.

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13.6: Colloids

- Colloids are intermediate particles between solution and suspension particles
  - Dispersion of colloids are call colloidal dispersions or simply colloids
  - Can be gases, liquids, or solids
- Colloid may consist of many atoms, ions, or molecules, or it may even be a single giant molecule
  - Range in diameter from 5 to 1000 nm
  - Large enough to scatter light effectively
- Colloid scatter light so light beam can be seen as it passes through
Scattering of light by colloidal particles is known as the Tyndall effect

- Hydrophilic and Hydrophobic Colloids
  - Colloids may be hydrophobic or hydrophilic
  - Hydrophilic colloids usually contain oxygen and nitrogen and often carry a charge
  - Hydrophobic colloids can be prepared in water if they are stabilized in some way
    - Adsorption of ions on their surface (Not absorption)
      - These ions can interact with water, thereby stabilizing the colloid
      - The mutual repulsion between colloid particles with absorbed ions of the same charge keeps the particles from colliding and getting larger
    - Hydrophobic colloids can also be stabilized by the presence of hydrophilic group on their surfaces
      - Substances with one end that is hydrophilic and one that is hydrophobic will stabilize a suspension of oil (hydrophobic) in water
        - The hydrophobic ends will interact with the hydrophobic particles (oil droplets) while the hydrophilic ends with water
  - Emulsify - “to form an emulsion,” a suspension of one liquid in another
    - A substance that aids in the formation of an emulsion is called an emulsifying agent

- Removal of Colloidal Particles
  - Colloids are too small to be separate by simple filtration
  - To remove colloids, the particles must be enlarged in a process called coagulation
    - Heating the mixture increases the particle motion and so the number of collisions
      - The particles increase in size after collision
    - Adding electrolytes neutralizes the surface charges of the particles thus removing the electrostatic repulsion between the particles
  - Semipermeable membranes can also be used to separate ions from colloidal particles because the ions can pass through the membrane but the colloidal particles cannot
    - This type of separation is known as dialysis