AP Chemistry
Mr Winter

Unit 3 Objectives
Properties of Substances and Mixtures

- Intermolecular and Interparticle Forces
  - Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when: the molecules are of the same chemical species, and the molecules are of two different chemical species.
    - London dispersion forces are a result of the Coulombic interactions between temporary, fluctuating dipoles. London dispersion forces are often the strongest net intermolecular force between large molecules.
    - Dispersion forces increase with increasing contact area between molecules and with increasing polarizability of the molecules.
    - The polarizability of a molecule increases with an increasing number of electrons in the molecule; and the size of the electron cloud. It is enhanced by the presence of pi bonding.
    - The term "London dispersion forces" should not be used synonymously with the term "van der Waals forces."
    - The dipole moment of a polar molecule leads to additional interactions with other chemical species.
    - Dipole-induced dipole interactions are present between a polar and nonpolar molecule. These forces are always attractive. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule.
    - Dipole-dipole interactions are present between polar molecules. The interaction strength depends on the magnitudes of the dipoles and their relative orientation. Interactions between polar molecules are typically greater than those between nonpolar molecules of comparable size because these interactions act in addition to London dispersion forces.
    - Ion-dipole forces of attraction are present between ions and polar molecules. These tend to be stronger than dipole- dipole forces.
    - The relative strength and orientation dependence of dipole-dipole and ion-dipole forces can be understood qualitatively by considering the sign of the partial charges responsible for the molecular dipole moment, and how these partial charges interact with an ion or with an adjacent dipole.
    - Hydrogen bonding is a strong type of intermolecular interaction that exists when hydrogen atoms covalently bonded to the highly electronegative atoms (N, O, and F) are attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different molecule, or a different part of the same molecule.
    - In large biomolecules, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule.
- Properties of Solids
  - Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.
    - Many properties of liquids and solids are determined by the strengths and types of intermolecular forces present. Because intermolecular interactions are broken when a substance vaporizes, the vapor pressure and boiling point are directly related to the strength of those interactions. Melting points also tend to correlate

with interaction strength, but because the interactions are only rearranged, in melting, the relations can be more subtle.

        - Particulate-level representations, showing multiple interacting chemical species, are a useful means to communicate or understand how intermolecular interactions help to establish macroscopic properties.
        - Due to strong interactions between ions, ionic solids tend to have low vapor pressures, high melting points, and high boiling points. They tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. They conduct electricity only when the ions are mobile, as when the ionic solid is melted or dissolved in water or another solvent.
        - In covalent network solids, the atoms are covalently bonded together into a three-dimensional network (e.g., diamond) or layers of two-dimensional networks (e.g., graphite). These are only formed from nonmetals: elemental (e.g., diamond, graphite) or binary compounds of two nonmetals (e.g., silicon dioxide and silicon carbide). Due to the strong covalent interactions, covalent solids have high melting points. Three-dimensional network solids are also rigid and hard, because the covalent bond angles are fixed. However, graphite is soft because adjacent layers can slide past each other relatively easily.
        - Molecular solids are composed of distinct, individual units of covalently-bonded molecules attracted to each other through relatively weak intermolecular forces. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. They do not conduct electricity because their valence electrons are tightly held within the covalent bonds and the lone pairs of each constituent molecule. Molecular solids are sometimes composed of very large molecules or polymers.
        - Metallic solids are good conductors of electricity and heat, due to the presence of free valence electrons. They also tend to be malleable and ductile, due to the ease with which the metal cores can rearrange their structure. In an interstitial alloy, interstitial atoms tend to make the lattice more rigid, decreasing malleability and ductility. Alloys typically retain a sea of mobile electrons and so remain conducting.
        - In large biomolecules or polymers, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule. The functionality and properties of such molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions.
- Solids, Liquids, and Gases
    - Represent the differences between solid, liquid, and gas phases using a particulate- level model.
        - Solids can be crystalline, where the particles are arranged in a regular three-dimensional structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both cases, the motion of the individual particles is limited, and the particles do not undergo overall translation with respect to each other. The structure of the solid is influenced by interparticle interactions and the ability of the particles to pack together.
        - The constituent particles in liquids are in close contact with each other, and they are continually moving and colliding. The arrangement and movement of particles are influenced by the nature and strength of the forces (e.g., polarity, hydrogen bonding, and temperature) between the particles.

        - The solid and liquid phases for a particular substance typically have similar molar volume because, in both phases, the constituent particles are in close contact at all times.
        - In the gas phase, the particles are in constant motion. Their frequencies of collision and the average spacing between them are dependent on temperature, pressure, and volume. Because of this constant motion, and minimal effects of forces between particles, a gas has neither a definite volume nor a definite shape.
- Ideal Gas Law
    - Explain the relationship between the macroscopic properties of a sample of gas or mixture of gases using the ideal gas law.
        - The macroscopic properties of ideal gases are related through the ideal gas law.

          $$PV = nRT$$
        - In a sample containing a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the total pressure of the sample is the sum of the partial pressures.

          $$P_A = P_{total} \times X_A$$

          where X_A = moles A/ total moles.

          $$P_{total} = P_A + P_B + P_c + \ldots$$
        - Graphical representations of the relationships between P, V, T, and n are useful to describe gas behavior.
- Kinetic Molecular Theory
    - Explain the relationship between the motion of particles and the macroscopic properties of gases with: the kinetic molecular theory (KMT), a particulate model, and a graphical representation.
        - The kinetic molecular theory (KMT) relates the macroscopic properties of gases to motions of the particles in the gas. The Maxwell-Boltzmann distribution describes the distribution of the kinetic energies of particles at a given temperature.
        - All the particles in a sample of matter are in continuous, random motion. The average kinetic energy of a particle is related to its average velocity.

          $$KE = \frac{1}{2} mv^2$$
        - The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample.
        - The Maxwell-Boltzmann distribution provides a graphical representation of the energies/ velocities of particles at a given temperature.
- Deviation From Ideal Gas Law
    - Explain the relationship among non-ideal behaviors of gases, interparticle forces, and/or volumes.
        - The ideal gas law does not explain the actual behavior of real gases. Deviations from the ideal gas law may result from interparticle attractions among gas molecules, particularly at conditions that are close to those resulting in condensation. Deviations may also arise from particle volumes, particularly at extremely high pressures.
- Solutions and Mixtures
    - Calculate the number of solute particles, volume, or molarity of solutions.
        - Solutions, also sometimes called homogeneous mixtures, can be solids, liquids, or gases. In a solution, the macroscopic properties do not vary throughout the sample. In a heterogeneous mixture, the macroscopic properties depend on location in the mixture.

        - Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory.

$$M = n_{solute}/L_{solution}$$

- Representations of Solutions
    - Using particulate models for mixtures: i. Represent interactions between components. ii. Represent concentrations of components.
        - Particulate representations of solutions communicate the structure and properties of solutions, by illustration of the relative concentrations of the components in the solution and drawings that show interactions among the components.
- Separations of Solutions and Mixtures
    - Explain the results of a separation experiment based on intermolecular interactions.
    - The components of a liquid solution cannot be separated by filtration. They can, however, be separated using processes that take advantage of differences in the intermolecular interactions of the components.
        - Chromatography (paper, thin-layer, and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components of the solution (the mobile phase) and with the surface components of the stationary phase.
        - Distillation separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.
- Solubility
    - Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.
        - Substances with similar intermolecular interactions tend to be miscible or soluble in one another.
- Spectroscopy and the Electromagnetic Spectrum
    - Explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.
    - Differences in absorption or emission of photons in different spectral regions are related to the different types of molecular motion or electronic transition:
        - Microwave radiation is associated with transitions in molecular rotational levels.
        - Infrared radiation is associated with transitions in molecular vibrational levels.
        - Ultraviolet/visible radiation is associated with transitions in electronic energy levels.
- Properties of Photons
    - Explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.
        - When a photon is absorbed (or emitted) by an atom or molecule, the energy of the species is increased (or decreased) by an amount equal to the energy of the photon.
        - The wavelength of the electromagnetic wave is related to its frequency and the speed of light.

$$c = \lambda v$$

        - The energy of a photon is related to the frequency of the electromagnetic wave through Planck's equation ($E = hv$).

- Beer-Lambert Law
    - Explain the amount of light absorbed by a solution of molecules or ions in relationship to the concentration, path length, and molar absorptivity.
        - The Beer-Lambert law relates the absorption of light by a solution to three variables.

$$A = \varepsilon bc$$

        - The molar absorptivity ε describes how intensely a sample of molecules or ions absorbs light of a specific wavelength. The path length b and concentration c are proportional to the number of absorbing species.
        - In most experiments the path length and wavelength of light are held constant. In such cases, the absorbance is proportional only to the concentration of absorbing molecules or ions.