Liquids, Solids, and Intermolecular Forces **(Chapter 11)**

Intermolecular Forces

1. Inter vs Intra Molecular Forces

Intra ≈ strong forces ***within*** molecules (covalent or ionic bonds)
(related to chemical reactivity of the substance)

Inter ≈ weaker forces ***between*** molecules
(determine the bulk physical properties of a substance)

2. **Types of Intermolecular Forces** -- Table 11.4
(in order of increasing strength)

- **Dispersion (London) forces**
  very weak "instantaneous induced dipole" forces
  between ***non-polar*** molecules or atoms (e.g., He, N_2, CO_2)

- **Dipole-Dipole forces**
  moderate forces between polar molecules (e.g., SO_2, PF_3)

- **H-bonding**
  especially strong dipole-dipole forces for compounds
  with H-F, H-O, or H-N bonds
  (e.g., HF, NH_3, H_2O, CH_3CH_2OH)

- ***Ion - Dipole forces***
  strong interactions between ionic and polar substances
  (e.g., NaCl in H_2O, AgS in liquid SO_2)

3. Bulk Properties of Liquids and Solids
(related to intermolecular forces)

melting and boiling points

compressibility

diffusion

surface tension

evaporation (liquid to gas)

sublimation (solid to gas)

Changes of State

1. Dynamic Equilibrium

changes of state (e.g., evaporation / condensation) involve process of ***dynamic equilibrium***:

$$\text{Liquid} \rightleftharpoons \text{Gas}$$

at equilibrium: forward rate = reverse rate (no net change with time)
(rate of evaporation = rate of condensation)

2. Vapor Pressure

pressure due to gas above surface of liquid

determined by strength of intermolecular forces
related to surface tension

boiling point -- temp at which vapor pressure = atmospheric pressure

normal boiling point -- temp at which vapor pressure = 1 atm

3. Le Châtelier's Principle

> When a dynamic equilibrium is upset by a stress, the system responds in a direction that tends to counteract the stress and, if possible, restore equilibrium.

e.g., vaporization / condensation:

$$\textbf{Liquid} + \textbf{heat} \rightleftharpoons \textbf{Gas}$$

if temp is raised (i.e., heat is added), the equilibrium shifts forward, hence, vapor pressure increases

4. Energy Changes during Changes of State

Heating and Cooling Curves (e.g., Figure 11.36)

plots of temperature vs amount of heat added (or removed)

horizontal regions are found during state changes (mp, bp, etc.)

Molar Heat quantities (heat absorbed by 1 mole of substance):

fusion (ΔH_{fusion}) -- melting of solid to liquid

vaporization ($\Delta H_{vaporization}$) -- evaporation of liquid to gas

sublimation ($\Delta H_{sublimation}$) -- solid to gas

{ all of these are affected by intermolecular forces }

e.g., $\Delta H_{vaporization}$ values:

H_2O = 43.9 kJ/mole, SO_2 = 24.3, CH_4 = 8.2

Relationship between $\Delta H_{vaporization}$ and Vapor Pressure

Clausius-Claperon Equation -- don't memorize!

$$\ln\left[\frac{P_1}{P_2}\right] = \frac{-\Delta H_{vap}}{R}\left[\frac{1}{T_2} - \frac{1}{T_1}\right]$$

Plot of vapor pressure vs 1/Temp is a straight line with slope equal to $-\Delta H_{vap} / R$ (see Figure 11.31).

5. Phase Diagrams (e.g., Figure 11.37)

phase diagram -- pressure vs temperature plot that shows:

three phase regions (solid, liquid, gas)

dividing lines (curves) -- equilibrium points between two phases

"triple point" -- T and P where all 3 phases coexist in equilibrium

"critical point" -- T and P upper limits on the liquid-gas curve

(e.g., for H_2O: critical T = 374℃ and critical P = 218 atm)

supercritical fluid -- state of matter beyond the critical point