Vapor Pressure of Liquids

- The vapor pressure of a liquid is measure of its “volatility”
- Vapor pressure is defined as the pressure exerted by the gas-phase molecules over a liquid
- Vapor pressure is a strong function of temperature—the higher the temperature, the higher the vapor pressure
Vapor Pressure and Boiling Point

The **boiling point** of a liquid is defined as that temperature when the vapor pressure of the liquid is equal to the total pressure of gas over the liquid.

The **normal boiling point** is defined as that temperature when the vapor pressure of the liquid is equal to 1 atm.

- For H$_2$O, the normal boiling point is 100.0 °C.
- For CH$_3$OH, the normal boiling point is 64.6 °C.
- For C2H5OH, the normal boiling point is 78.3 °C.
Vapor Pressure and Boiling Point

- The vapor pressure of a liquid is related to its heat of vaporization, $\Delta H_{\text{vap}}$, through the Clausius-Clapeyron Equation:

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

- If $P_1 = 1$ atm, then $T_1$ is the normal boiling point, and we can determine the vapor pressure at any other temperature.
Vapor Pressure and Boiling Point

Example: Determine the vapor pressure of H₂O at 50.0 °C

ΔH_{vap} = 40.79 \text{ kJ mol}^{-1}

T_b = 100.0 °C

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

T_1 = 100.0 + 273.2 = 373.2 K \quad P_1 = 760 \text{ Torr}

T_2 = 50.0 + 273.2 = 323.2 K

P_2 = (760 \text{ Torr})\exp\left\{-\frac{40,790 \text{ J mol}^{-1}}{8.314 \text{ J mol}^{-1} \text{K}^{-1}} \left[\frac{1}{323.2 \text{ K}} - \frac{1}{373.2 \text{ K}}\right]\right\} = 99.4 \text{ Torr}
Phase Changes

- Changes in the phase of a substance (solid, liquid, or vapor) occur when the amount of kinetic energy in the substance is changed.

- When energy is put into the system from the surroundings, we get:
  
  - Melting—transition from solid $\rightarrow$ liquid
  - Boiling—transition from liquid $\rightarrow$ vapor
  - Sublimation—transition from solid $\rightarrow$ vapor

- When energy is removed from the system, we get condensation, freezing, or deposition.
Phase Changes

- The energy associated with a phase transition is called the enthalpy of:
  - vaporization, $\Delta H_{\text{vap}}$—boiling
  - fusion, $\Delta H_{\text{fus}}$—melting
  - sublimation, $\Delta H_{\text{sub}}$—sublimation

- $\Delta H_{\text{vap}}(\text{H}_2\text{O}) = 40.79$ kJ mol$^{-1}$: you must put 40,790 J of energy in to boil 1 mole of water at its normal boiling point

- If 1 mole of water condenses, you get 40,790 J of energy out of the system
Heating Curves

If you begin with a pure solid and add energy to the system, we can plot the temperature of the system as a function of time to produce a heating curve.
Phase Diagrams

- We can plot the different phases of a substance as a function of temperature and pressure to produce a phase diagram.
Types of Solids

There are different types of solids depending on the bonding and attractive forces that occur within each type.

1. Ionic solids: one or more electrons are transferred from a metal to a non-metal, and the resulting ions are held together by electrostatic attraction.

   \[ \text{NaCl, CaCl}_2, \ (\text{NH}_4)_3\text{PO}_4 \]
Types of Solids

2. Metallic solids: the valence atomic orbitals of the individual metal atoms combine to form molecular orbitals in which the electrons are no longer associated with an individual nucleus, but rather are free to move throughout the entire metallic solid

   Fe, Ag, Au, Cu, alloys
Types of Solids

3. Molecular solids: individual molecules are held together by intermolecular attractive forces such as dispersion forces, dipole-dipole interactions, or hydrogen bonding

\[ \text{H}_2\text{O(ice)}, \text{CO}, \text{CO}_2, \text{CH}_3\text{COCH}_3 \text{ (acetone)} \]
4. Network solids: atoms are held together in an network by covalent bonds with a very specific solid crystalline structure

The network may be either one-, two-, or three-dimensional

\[ \text{C(diamond), C(graphite), SiO}_2\text{(quartz), KAISi}_3\text{O}_8 \text{ (K-feldspar)} \]
5. Amorphous solids: atoms are held together in a three-dimensional network by covalent bonds, but the solid does not have a specific crystalline structure.

$\text{SiO}_2\text{(glass)}$, polyethylene, nylon