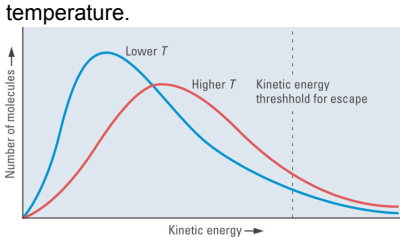
# Liquids, Solids & Materials

Chapter 11

## Vapor Pressure

- Liquid in open container will evaporate.
- Liquid volatility increases with increasing temperature.





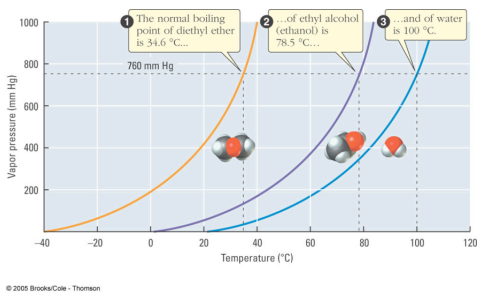

## Vapor Pressure

- Liquid in closed, evacuated container will evaporate until a dynamic equilibrium is reached.

(rate of vaporization = # rate of condensation)

- Pressure of gas above the liquid is known as the vapor pressure.

## Vapor Pressure





## Vapor Pressure

Vapor pressure differences between different liquids arise from differences in the strengths of intermolecular forces.

Stronger intermolecular forces result in lower vapor pressures.

## Vapor Pressure & Boiling Point

In an open container:

Temperature at which liquid's vapor pressure equals atmospheric pressure — boiling point

When atmospheric pressure equals 1 atm — normal boiling point

## Clausius-Clapeyron Equation

Describes relationship between vapor pressure and temperature.

$$\ln P = \frac{-\Delta H_{vap}}{RT}$$

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

## Phase Changes

- Vaporization and Condensation

Liquid $\underset{\text{heat of condensation}}{\overset{\text{heat of vaporization}}{\rightleftharpoons}}$ Gas

$\Delta H_{vaporization} = -\Delta H_{condensation}$

## Phase Changes

TABLE 11.2 Molar Enthalpies of Vaporization and Boiling Points for Some Common Substances

| Substance | Number of Electrons | $\Delta H_{vap}^{\circ}$ (kJ/mol)[a] | Boiling Point (°C)[a] |
|---|---|---|---|
| **Polar molecules** | | | |
| HF | 10 | 25.2 | 19.7 |
| HCl | 18 | 17.5 | −84.8 |
| $NH_3$ | 10 | 25.1 | −33.4 |
| $H_2O$ | 10 | 40.7 | 100.0 |
| $SO_2$ | 32 | 26.8 | −10.0 |
| HBr | 36 | 19.3 | −66.5 |
| HI | 54 | 21.2 | −35.1 |
| **Noble gases** | | | |
| He | 2 | 0.08 | −269.0 |
| Ne | 10 | 1.8 | −246.0 |
| Ar | 18 | 6.5 | −185.9 |
| Xe | 54 | 12.6 | −107.1 |
| **Nonpolar molecules** | | | |
| $H_2$ | 2 | 0.90 | −252.8 |
| $O_2$ | 16 | 6.8 | −185.0 |
| $F_2$ | 18 | 6.54 | −188.1 |
| $Cl_2$ | 34 | 20.39 | −34.6 |
| $Br_2$ | 70 | 29.54 | 59.6 |
| $CH_4$ (methane) | 10 | 8.9 | −161.5 |
| $CH_3{-}CH_3$ (ethane) | 18 | 15.7 | −88.6 |
| $CH_3{-}CH_2{-}CH_3$ (propane) | 26 | 19.0 | −42.1 |
| $CH_3{-}CH_2{-}CH_2{-}CH_3$ (butane) | 34 | 24.3 | −0.5 |

## Phase Changes

- Melting and Freezing

Solid $\underset{\text{heat of crystallization}}{\overset{\text{heat of fusion}}{\rightleftharpoons}}$ Liquid

$\Delta H_{fusion} = -\Delta H_{crystallization}$

## Phase Changes

TABLE 11.3 Melting Points and Enthalpies of Fusion of Some Solids

| Solid | Melting Point (°C) | Enthalpy of Fusion (kJ/mol) | Type of Intermolecular Forces |
|---|---|---|---|
| **Molecular solids: Nonpolar molecules** | | | |
| $O_2$ | −248 | 0.445 | These molecules have only London forces (which increase with the number of electrons). |
| $F_2$ | −220 | 1.020 | |
| $Cl_2$ | −103 | 6.406 | |
| $Br_2$ | −7.2 | 10.794 | |
| **Molecular solids: Polar molecules** | | | |
| HCl | −114 | 1.990 | All of these molecules have London forces enhanced significantly by dipole-dipole forces. $H_2O$ also has significant hydrogen bonding. |
| HBr | −87 | 2.406 | |
| HI | −51 | 2.870 | |
| $H_2O$ | 0 | 6.020 | |
| $H_2S$ | −86 | 2.395 | |
| **Ionic solids** | | | |
| NaCl | 800 | 30.21 | All ionic solids have strong attractions between oppositely charged ions. |
| NaBr | 747 | 25.69 | |
| NaI | 662 | 21.95 | |



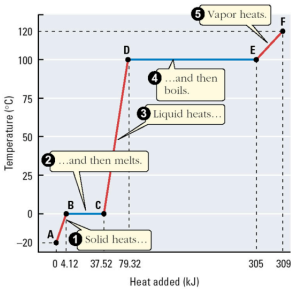
## Phase Changes

- Sublimation and Deposition

Solid $\underset{\text{heat of deposition}}{\overset{\text{heat of sublimation}}{\rightleftharpoons}}$ Gas

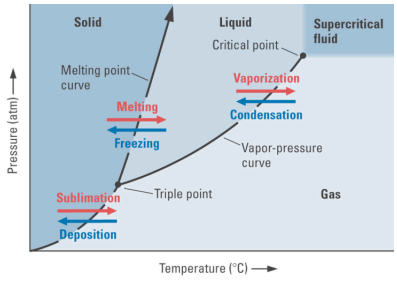
$\Delta H_{sublimation} = -\Delta H_{deposition}$

## Heating Curves



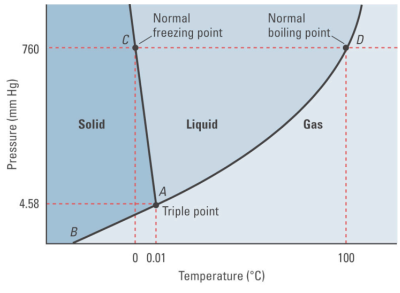



## Phase Diagrams






## Phase Diagrams - $H_2O$



## Phase Diagrams - $CO_2$