12.4 Latent Heat and Phase Changes

Recall: \[ Q = c \cdot m \cdot \Delta T \]
\[ \frac{Q}{m} = c \cdot \Delta T \]

\[ Q = m \cdot L \]  
- \( L \) “latent heat”
- \( m \) the phases of water

\[ \frac{Q}{m} = c(50^\circ C) = 2000 \frac{J}{kg^\circ C} \]

\[ \frac{Q}{m} = L_{\text{ice}} = 3.35 \times 10^5 \frac{J}{kg} \]

\[ \frac{Q}{m} = c(100^\circ C) = 4186 \frac{J}{kg^\circ C} \]
\[ = 4.186 \times 10^5 \frac{J}{kg} \]

\[ \frac{Q}{m} = L_{\text{vap}} = 22.6 \times 10^5 \frac{J}{kg} \]
Ex. / 2 kg water (99°C) \rightarrow 2 kg vapor (100°C)

\[ Q_{\text{tot}} = Q_w + Q_{\text{vap}} \]

\[ = c_m \Delta T + \frac{\Delta U}{\Delta T} \]

\[ = 4.186 \frac{\text{J}}{\text{kg} \cdot ^\circ \text{C}} (2 \text{kg})(10^0 \circ \text{C}) + (2 \text{kg})(326 \times 10^6 \frac{\text{J}}{\text{kg}}) \]

\[ = 4.53 \times 10^6 \text{ J} \]
Chapter 13 / Heat Transfer

3 types:
- Convection - bulk movement of fluid
- Conduction - microscopically within a substance
- Radiation - electromagnetic waves

Good conductors - metals
- air
- Not - styrofoam, wood, plastic

Radiation - sun, microwave, cellphone
13.2 Conduction - heat transfer microscopically via neighboring atoms/electrons

- local collisions
- transfer vibrations
- electron motion

$Q_{\text{conduct}} = \frac{KA(\Delta T)}{L}$

[\text{[K]} = \text{WmsC}^\circ]$
13.3 Radiation

→ e.m. waves (quanta: photons)

☆ perfect

"black body" ⇒ all radiation is absorbed

☆ perfect absorber is also a perfect emitter

(none is reflected)
radiated heat in equilibrium

\[ Q = e \sigma T^4 A(t) \]

- \( e \) is the emissivity, \( 0 < e < 1 \)
- \( A(t) \) is the cross-sectional area
- \( T \) is the temperature
- \( \sigma = 5.67 \times 10^{-8} \text{ J m}^{-2} \text{K}^{-4} \)

\[ A = 4\pi r^2 \]

Source
transferred Power \( = \frac{Q}{t} \) = \( \left\{ \begin{align*} \frac{eGAT^4}{\kappa A \Delta T} & \text{ radiation} \\ \frac{\kappa A}{L} \Delta T & \text{ conduction} \end{align*} \right. \\

\text{net radiated (absorbed) power} \\
\mathbf{P}_{\text{net}} = eG A (T_4^4 - T_0^4) \\
\text{body} \quad \text{environment}
Chapter 14/ Ideal Gas Law: Universal Law & Kinetic Theory

14.1 Molecular Mass, Mole, and \( N_A \)

**Def: Atomic Mass Unit**

\[
1\text{u} = \frac{1}{12} m(^{12}\text{C}) = 1.66 \times 10^{-24} \text{ kg}
\]

Defined such that \( m(^{12}\text{C}) = 12\text{u} \)

- **R_{nucleus}**
  - \( 2.5 \text{ fm} = 2.5 \times 10^{-15} \text{ m} \)

- **R_{atom}**
  - \( 0.7 \times 10^{-10} \text{ m} \)

- electron cloud
Def. amount of substance

$1$ mole of substance $\equiv$ containing
as many molecules as $12g$ of $^{12}C$

$\#\text{mole} = n = \frac{N}{N_A}$  

$N_A = 6.022 \times 10^{23}$ particles/mole

\[ \frac{m_{\text{atom}} \cdot N}{\text{mole } N_A} = \frac{M_{\text{substance}}}{M_{\text{mole}}} \]  

$M_{\text{mole}} \rightarrow$ mass of $1$ mole of substance

$\rightarrow$ atomic mass units in grams
e.g. $\text{H}_2\text{O}$

\[ M_{\text{mole}} = (2 \cdot 1.008 + 15.999) \text{g} = 18.015 \text{g} \]

\[ m_\text{H} = 1.008 \text{u} \]
\[ m_\text{O} = 15.999 \text{u} \]

14.2 **Ideal Gas Law**

\[ PV = nRT \]

- $P$: pressure
- $V$: volume
- $n$: number of moles
- $R$: universal gas constant
- $T$: temperature

$R$ is universal gas constant:

\[ R = 8.31 \text{ J} \text{m}^{-2} \text{mol}^{-1} \text{K}^{-1} \]

Boltzmann constant:

\[ k = \frac{R}{N_A} = 1.38 \times 10^{-23} \text{ J/K} \]

\[ k = \frac{R}{N_A} \Rightarrow R = kN_A \]

\[ PV = n(kN_A) \cdot T = NkT \]

$N$: number of molecules
\[ PV = nRT \]

**Constant** \( P, n \) \( \Rightarrow \)

\[ \frac{P}{nR} = \text{const} = \frac{I}{V} \]

Charles' Law

**Constant** \( T, n \) \( \Rightarrow \)

\[ \frac{V_i}{T_i} = \frac{V_f}{T_f} \]

Boyle's Law

\[ nRT = \text{const} = PV \]

\[ P_i V_i = P_f V_f \]
14.3 Kinetic Theory of Gases

- To calculate pressure from microscopic gas particle motion

Need:
(a.) Particle velocities
(b.) Force exerted on container walls via elastic collisions

- Most probable speed

\[ T = 300 \text{ K} \]

\[ T = 1200 \text{ K} \]

- Average speed:

\[ V_{rms} = \sqrt{\frac{3kT}{m}} \]

- Examples:
  - 485 m/s at 300 K
  - 970 m/s at 1200 K
  - \( (O_2) \)
b.) avg. Force on 1 container wall by 1 particle

\[ F_{\text{wall}} = - F_{\text{particle}} = - ma_{\text{particle}} \]

\[ = -m \frac{\Delta v}{\Delta t} = \frac{1}{3} \frac{\Delta P}{\Delta t} \]

\[ \Delta v = \frac{p_f - p_i}{m} = 2mv_{\text{rms}} \]

\[ v_{\text{rms}} = \frac{2L}{\Delta t} \Rightarrow \Delta t = \frac{2L}{v_{\text{rms}}} \]

all particles: \[ F_{\text{wall}} = \frac{N}{3} \frac{m v_{\text{rms}}^2}{v_{\text{rms}}} \]

\[ P_{\text{wall}} = \frac{N}{3} \frac{m v_{\text{rms}}^2}{L \cdot L^2} = \frac{N}{3V} \left( \frac{1}{3} m v_{\text{rms}}^2 \right) \]

\[ P = \frac{2N}{3V} \text{KE} \rightarrow \text{KE} = \frac{3}{2} \frac{PV}{N} = \frac{3}{2} kT \]