Lecture 4

: thermal properties of matter :

- Thermal Contact ⇒ when energy is exchanged between two objects
- Thermal equilibrium ⇒ when objects are in contact but there is no exchange of energy

Zero Law of Thermodynamics

↳ if bodies A & B are separately in thermal equilibrium with a third body, C, then A & B will be in thermal equilibrium with each other if placed in thermal contact.

↳ The zeroth law means you can measure whether two bodies have the same temperature without thermal contact, (with a thermometer)

* ↳ if two objects are in thermal equilibrium → they have the same temperature.

The Celsius Scale

* ↳ Temperature readings T_C ⇒ °C (degree celsius)
  ↳ Temperature difference ΔT_C ⇒ C° (celsius degree)

The Fahrenheit scale

* ↳ Temperature readings T_F ⇒ °F
  ↳ Temperature difference ΔT_F ⇒ F°

The Kelvin Scale

↳ Temperature readings and difference are both K

Conversions

$T_F = \frac{9}{5}T_C + 32°$ $T_C = \frac{5}{9}(T_F - 32°)$

$\Delta T_F = \frac{9}{5}\Delta T_C$ $\Delta T_C = \frac{5}{9}\Delta T_F$

$\underbrace{T}_{T_K} = T_C + 273.15K$ $\underbrace{\Delta T}_{\Delta T_K} = \Delta T_C$

Characteristics of a Gas

- assume the shape and volume of the container
- most compressible state of matter
- have low densities
- have very weak intermolecular forces

- Variables that describe the behavior of a given quantity of gas :
  - Pressure (P) → N/m^2 → Pa
  - Volume (V) → L
  - Temperature (T) → k
  - number of moles of a gas (n)

Boyle's Law

- $PV = \text{Constant}$

$P_1V_1 = P_2V_2$

- held at constant temperature

Charles' Law

- $\frac{V}{T} = \text{Constant}$

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

- held at constant pressure

Gay-Lussac's Law

- $\frac{P}{T} = \text{Constant}$

$\frac{P_1}{T_1} = \frac{P_2}{T_2}$

- held at constant volume

Ideal Gas Law

$$\underset{\text{Pressure KPa}}{P}\,\underset{\text{volume L}}{V} = \underset{\text{moles}}{n}\,\overset{8.314\ J/Kmol}{R}\,\underset{\text{temperature K}}{T}$$

all gases are ideal at low pressure

$$PV = \underset{\text{molecules}}{N}\,\underbrace{k_B}_{1.38\times10^{-23}\ J/k}T \qquad k_B = \frac{R}{N_A}$$

Molecular Interpretation of Temperature

↳ 3D Kinetic theory of gases

$$PV = \frac{2}{3} N K_{av} \leftarrow \text{average kinetic energy of molecule}$$

$$K_{av} = \frac{1}{2} \underset{\text{mass of molecule}}{m_0} \bar{V}^2 \leftarrow \text{speed}^2 \qquad m_0 = \frac{M_W}{N_A}$$

$$* \quad \therefore \frac{1}{2} m_0 \bar{V}^2 = \frac{3}{2} \underbrace{k_B T}_{\text{Thermal energy of gas}}$$

$$\frac{3}{2} \cdot \frac{\frac{2}{3} N\left(\frac{1}{2} m_0 \bar{V}^2\right)}{2} = \frac{N k_B T \cdot \frac{3}{2}}{2}$$

$$\frac{1}{2} m_0 \bar{V}^2 = \frac{3}{2} k_B T$$

↳ T↑ V↑

$$\sqrt{\bar{V}^2} = rms \rightarrow \text{root mean square}$$

$$\sqrt{\bar{V}^2} = \sqrt{\frac{3 k_B T}{m_0}} \qquad k_B = \frac{R}{N_A}, \quad m_0 = \frac{M_W}{N_A}$$

$$= \sqrt{\frac{3 \frac{R}{N_A} T}{\frac{M_W}{N_A}}}$$

$$V_{rms} = \sqrt{\frac{3RT}{M_W}}$$

- Thermal Expansion
  - ↳ heated = expand
  - ↳ Cooled = negative expansion (contract)

- Linear Expansion of solids
  - ↳ ⇒ the change in one dimension of a solid (length, width, thickness)
  - ↳ The amount the solid expands or contract depends on the material, temperature change and the initial length
  - ↳ the stronger the bonds between atoms of objects; the less likely they will expand or contract

$\boxed{1D}$ $$\Delta L = \alpha L_0 \Delta T$$

ΔT: $(T_f - T_i)$, °c/k

α: thermal coefficient of linear expansion, unit (K^{-1}) or (C^{-1})

To find final length after temp. Change: $L = L_0(1 + \alpha \Delta T)$

- Area Expansion of Solids

$\boxed{2D}$ $$\Delta A = \beta A_0 \Delta T \quad \text{or} \quad \frac{\Delta A}{A_0} = \beta \Delta T$$

β: thermal coefficient of area expansion, K^{-1} or C^{-1}

To find final area after temp. Change: $A \approx A_0(1 + 2\alpha \Delta T)$

in Area β for isotropic solids $= 2\alpha$

$$\Delta A \approx (2\alpha) A_0 \Delta T$$

isotropic solids ⇒ solids that have the same exact properties in all different directions (density)

- Volumetric Expansion of Solids

$\boxed{3D}$ $$\Delta V = \gamma V_0 \Delta T$$

γ: thermal coefficient of ~~volume~~ expansion, K^{-1} or C^{-1}

To find final volume after temp. Change: $V \approx V_0(1 + 3\alpha \Delta T)$

in volume for isotropic solids

$\gamma = 3\alpha$

$$\Delta V \approx (3\alpha) V_0 \Delta T$$

Specific Heat Capacity (c)

$$Q = Cm\Delta T$$

amount of heat energy (J); C (J/kg°C); m: mass

or $Q = Cm(T_f - T_i)$

↳ if ΔT = +ive ⇒ system gains energy

ΔT = -ive ⇒ system loses energy

↳ When two substances at different temperatures are mixed Conservation energy equals zero ⇒ $Q_{gain} + Q_{lost} = 0$

$$Q_{gain(w)} + Q_{lost(x)} = m_w C_w (T_f - T_w) + m_x C_x (T_f - T_x)$$

$$0 = m_w C_w (T_f - T_w) + m_x C_x (T_f - T_x)$$

$$C_x = \frac{m_w C_w (T_f - T_w)}{m_x (T_x - T_f)}$$

Heat Transfer

↳ *heat can be transferred by three different ways:*

① Heat Conduction

↳ occurs in all states of matter but best in solids

↳ happens by particles colliding with each other

$$H = \frac{\Delta Q}{\Delta T}$$

$$H = kA\frac{(T_{hot} - T_{cold})}{L}$$

H: heat transfer (watt); k: Thermal Conductivity (W/mk); L: separation distance between hot & cold

↳ materials with high thermal conductivity are called conductors

② Heat Convection

↳ heat transfer by mass motion of a fluid

③ Heat Radiation / Infra-red Radiation

↳ the heat transfer directly from the source to the object by a wave travelling as rays

↳ objects that are hotter than their

$$P = e\sigma A(T^4 - T_s^4)$$

σ → 5.67×10^{-8} watt/m^{2}K^4

P → Power (watt)

e → emissivity $= 1$

A → Area m^2

T → temp of radiator K

T_s → temp. of surrounding K

Wien Displacement law:

$$\lambda = \frac{B}{T}$$

B → 2.898×10^{-3} mK

λ → wave length m

T → Temp. K