BRAIN MAP

THERMAL PROPERTIES OF MATTER, THERMODYNAMICS & KINETIC THEORY

Heat and temperature are not the same thing. Temperature of a body is the degree of hotness or coldness whereas heat is a form of energy that flows between two bodies by virtue of temperature difference between

Thermal Properties of Matter

Heat and Temperature

- Heat is a form of energy which produces in us the sensation of warmth.
- Temperature is a relative measure of hotness or coldness of a body.
- $\frac{T_C + 0}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273.15}{100} = \frac{T_R - 0}{80}$

  where T_C, T_F, T_K and T_R are the temperatures on Celcius, Fahrenheit, Kelvin and Reaumur scales respectively.

Thermal Expansion

- **Coefficient of linear expansion (α) :** Increase in length per unit length per unit rise in temperature.
  $$\alpha = \frac{BL}{L\Delta T}$$
- **Coefficient of area expansion (β) :** Increase in area per unit area per unit rise in temperature.
  $$\beta = \frac{BA}{A\Delta T}$$
- **Coefficient of volume expansion (γ) :** Increase in volume per unit volume per unit rise in temperature.
  $$\gamma = \frac{BV}{V\Delta T}$$
- **Relation between α, β and γ :** $6\alpha = 3\beta = 2\gamma$

Important Definitions

- **Specific heat capacity (c) :** Amount of heat required to raise the temperature of unit mass of the substance through one degree.
  $$c ; \frac{Q}{m\Delta T}$$
- **Molar heat capacity (C) :** Amount of heat required to raise the temperature of one mole of a substance through one degree.
  $$C ; \frac{Q}{n\Delta T}$$
- **Water equivalent (w) :** Quantity of water which would be raised through 1°C by the amount of heat required to raise the temperature of the body through 1°C.
  $$w = mc$$
- **Latent heat (L) :** Amount of heat required to change the state of a unit mass of a substance without rise in temperature.
  $$L ; \frac{Q}{m}$$
  Latent heat of fusion (L_f) corresponds to solid to liquid phase change whereas latent heat of vapourisation (L_v) corresponds to liquid to gas phase change.

Heat Transfer

- Heat Q that flows across the opposite faces of a rod in time t,
  $$Q ; KA\frac{dT}{dx}t$$
  where A is area of cross-section, $\frac{dT}{dx}$ is temperature gradient and K is coefficient of thermal conductivity.

Newton's Law of Cooling

- Rate of cooling of a body is proportional to the excess temperature of the body over the surroundings

  i.e. $\frac{dQ}{dt} ; -k(T_2 - T_1)$

Thermodynamics

First Law of Thermodynamics

- $dQ = dU + dW$

  where dQ is amount of heat which is taken as positive when heat is supplied to a system and negative when heat is drawn from the system

  dU is change in internal energy, taken as positive when temperature increases and negative when temperature decreases,

  dW is amount of work done, taken as positive when work is done by the system and negative when work is done on the system.

Thermodynamic Processes

- **Isothermal :** Temperature constant.
  $(dQ = dW)$
- **Adiabatic :** No heat flow between the system and surroundings.
  $(dU = -dW)$
- **Isobaric :** Pressure constant.
- **Isochoric :** Volume constant.
  $(dQ = dU)$

Adiabatic and Isothermal Processes

- For an adibatic process,
  PV^{ε} = constant, $TV^{(\gamma-1)}$ = constant,
  $P^{(1-\gamma)}T^{\gamma}$ = constant
  $$W = \frac{nR(T_1 + T_2)}{(\gamma - 1)}$$
- For an isothermal process,
  $$W ; nRT\ln\frac{V_2}{V_1}$$
- Slope of adiabatic curve
  = γ(slope of isothermal curve)

Heat Engine and Refrigerator

- Net work done (W) = Heat absorbed by the source (Q_1) – Heat rejected to the sink (Q_2)
- Efficiency of a heat engine,
  $$\phi = \frac{W}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$
- Coefficient of performance of a refrigerator,
  $$\upsilon = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

Entropy

- Entropy (S) is the measure of disorder in a system.
  $$\Delta S = \frac{BQ}{T}.$$
- For irreversible processes, $\Delta S > 0$
- For reversible processes, $\Delta S = 0$
- Process where $\Delta S < 0$ is not possible.

Kinetic Theory

Ideal Gas Laws

- **Boyle's law :** At constant T,
  $P \propto 1/V$, PV = constant
- **Charles' law :** At constant P,
  $V \propto T$, V/T = constant
- **Gay-Lussac's law :** At constant V,
  $P \propto T$, P/T = constant
- **Ideal gas equation :**
  $$PV = nRT = k_B NT.$$

Pressure and Kinetic Energy

- Pressure exerted by an ideal gas
  $$P ; \frac{1}{3}mnv^2_{rms} = \frac{1}{3}\frac{M}{V}v^2_{rms} = \frac{1}{3}\rho v^2_{rms}$$
- Average kinetic energy per molecule of the gas
  $$E ; \frac{1}{2}mv^2_{rms} = \frac{3}{2}k_B T$$
- Relation between P and E : $PV = \frac{2}{3}E$

Speed of a Gas Molecule

- Most probable speed,
  $$v_{mp} ; \sqrt{\frac{2k_BT}{m}} = \sqrt{\frac{2RT}{M}}$$
- Average speed,
  $$v_{av} ; \sqrt{\frac{8k_BT}{\pi m}} = \sqrt{\frac{8RT}{\pi M}}$$
- Root mean square speed,
  $$v_{rms} ; \sqrt{\frac{3k_BT}{m}} = \sqrt{\frac{3RT}{M}}$$

Relation between C_P, C_V, γ, f and R

- $C_V ; \frac{f}{2}R$
- $C_P ; \frac{f}{2}R + R$
- $\varepsilon ; \frac{C_P}{C_V}$
- $\varepsilon = 1 + \frac{2}{f}$
- $C_P + C_V = R$

  where f is the number of degrees of freedom.

Values of C_P, C_V and γ

- For monoatomic gases
  $C_V ; \frac{3}{2}R$, $C_P = \frac{5}{2}R$, $\gamma = \frac{5}{3}$
- For diatomic gases :
  $C_V ; \frac{5}{2}R$, $C_P = \frac{7}{2}R$, $\gamma = \frac{7}{5}$
- For triatomic gases (linear molecule)
  $C_V ; \frac{7}{2}R$, $C_P = \frac{9}{2}R$, $\gamma = \frac{9}{7}$
- For triatomic gases (non-linear molecule)
  $C_V ;$ $3R$, $C_P = 4R$, $\gamma = \frac{4}{3}$

Mean Free Path

- Average distance travelled by a gas molecule between two successive collisions
  $$\varphi = \frac{k_BT}{\sqrt{2}\pi d^2 P} = \frac{1}{\sqrt{2}\pi d^2 n}$$

Blackbody Radiation

- **Wein's displacement law :** $\lambda_m T$ = constant
- **Stefan-Boltzmann law :** For a perfect radiator at temperature T, the energy emitted per unit time, $H = A\sigma T^4$

  For a perfect radiator at temperature T, with surroundings at T_S, $H = \sigma A(T^4 - T_S^4)$

  For a body with emissivity e, $H = e\sigma A(T^4 - T_S^4)$