



PHYSICS

classmate

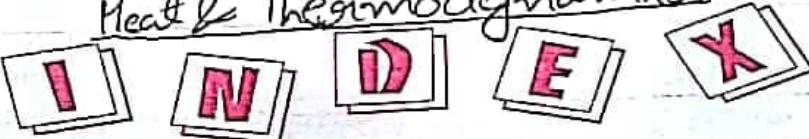
Heat & Thermodynamics
{Basic Theory}

1

Widely known as one of the most beautiful lakes in the world, Lake Atitlán in Guatemala, Central America, is surrounded by steep volcanoes and Mayan settlements.

Notebook

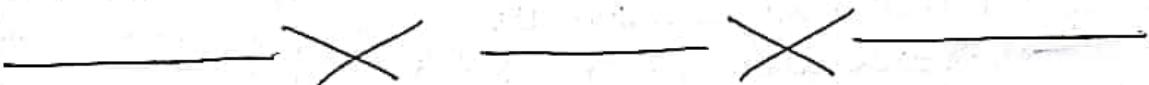
Heat & Thermodynamics



NAME: Aditya STD.: XI SEC.: A ROLL NO.: 01 SUB.: Physics

Introduction to Thermal physics

1. Heat & Temperature
2. Kinetic theory of gas
3. Laws of Thermodynamics
4. Specific heat Capacities of gas
5. Heat transfer



1 Heat & Temperature

Hot & cold Bodies (In short, miniatu)

* The transfer of energy from a hot body to a cold body is a nonmechanical process.

The energy that is transferred from one body to other, without any mechanical work involved is called heat.

Zenoth Law of thermodynamics

(i) If two bodies A and B are in thermal equilibrium and A and C are also in thermal equilibrium, then B and C are also in thermal equilibrium.

* All bodies in thermal Equilibrium are assigned equal temperature.

* Heat flows from the body at higher temperature to the body at lower temperature.

Hot Body	Energy \rightarrow	Cold Body
	flow =	

Defining Scale of Temperature: Mercury & resistance thermometers

For defining Scale of temperature we have to look for a measurable property of the substance which monotonically changes with temperature.

① Mercury Thermometer

→ We arbitrarily assign a temperature t_1 to the ice point and t_2 to the steam point.

→ Let the length of the Hg column is l_1 when the bulb is kept in melting ice and it is l_2 when the bulb is kept in boiling H_2O .

$$\text{rate} = \frac{l_2 - l_1}{t_2 - t_1} = \text{constant}$$

$$t = at + b$$

* On centigrade system

$$* \text{Ice point} = 0^\circ \text{C}$$

$$* \text{Steam point} = 100^\circ \text{C}$$

$$t = \frac{d - d_0}{d_{100} - d_0} \times 100 \text{ degree}$$

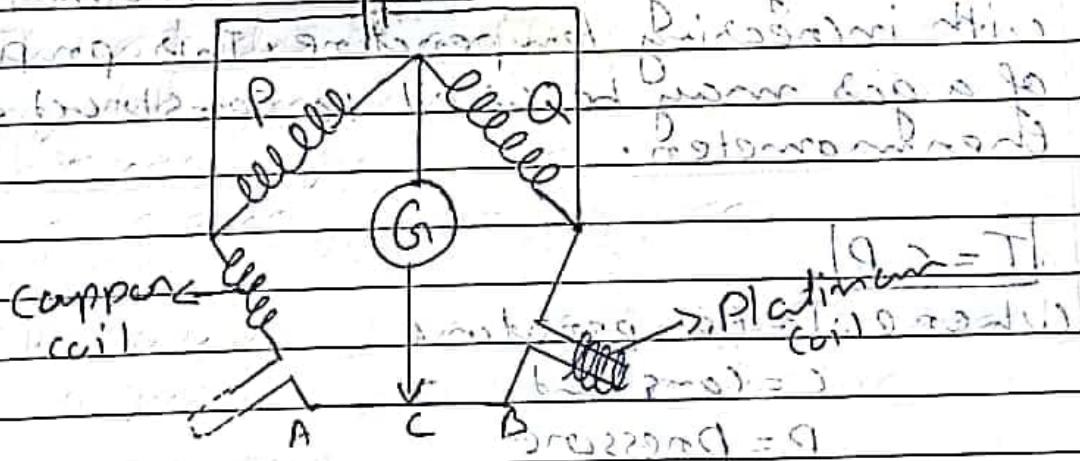
* In Fahrenheit System:

* ice point = 32°F

* steam point = 212°F

$$F = 32 + \frac{9}{5} C$$

Platinum Resistance Thermometer

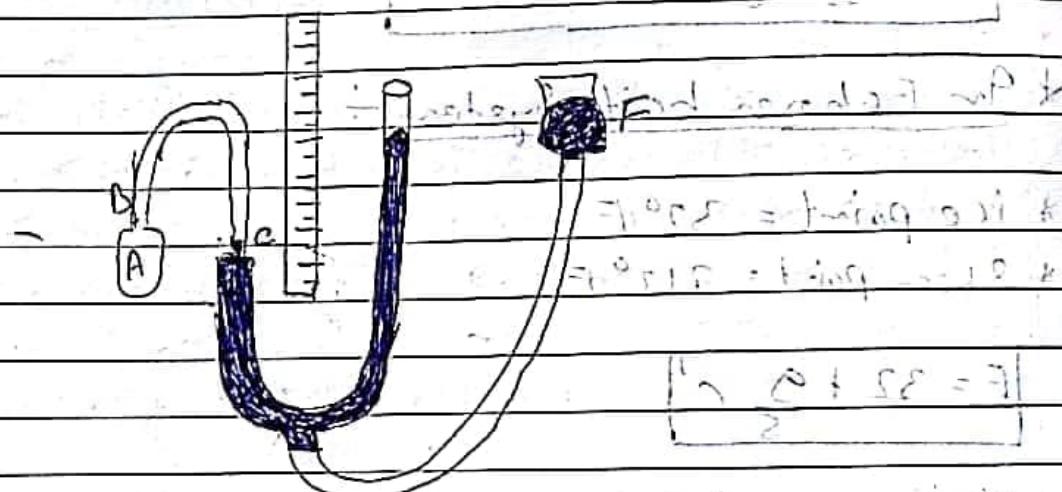


* Let resistance of copper = R
Resistance of Platinum = $R_0 + \alpha T$

* $A C = x$

$$\rightarrow t = \frac{x_0 - x_0}{x_{100} - x_0} \times 100 \text{ degree} = 9.9 \text{ m.s.d.}$$

Constant volume Gas Thermometer



→ Pressure of a gas increases monotonically with increasing temperature. This property of a gas may be used to construct a thermometer.

$$T = cP$$

where, T = Temperature

c = Constant

P = Pressure

$$T = P \times 273.16 \text{ K}$$

P_{tr}

where, P_{tr} = Pressure at triple point of water. $(T = 0^\circ\text{C})$

$$\frac{T = P - P_0 \times 100^\circ C}{P_{100} - P_0}$$

Ideal gas Temperature scale

$$T = \lim_{P_{\text{ext}} \rightarrow 0} \frac{P}{P_{\text{ext}}} \times 273.16 \text{ K} \quad \textcircled{1}$$

- * The temperature scale defined by eq ① is called ideal gas temperature scale and is independent of the gas chosen.

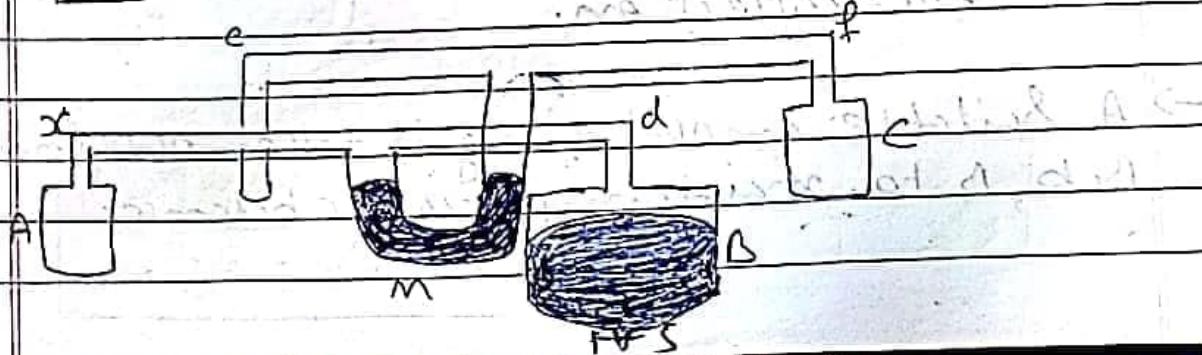
Ideal gas Equation

$$PV = nRT$$

Where $R = 8.31 \text{ J/mol}\cdot\text{K}$

Callendar's compensated constant pressure thermometer

Setup



* Setup description

- A and B are bulb containing some ideal gas in same amount.
- End of each capillary tube of same volume.
- M is manometer connected to the two capillary tube A and B directly without any intermediate bulb. It has a tap to take out N₂.
- Capillary tube A is connected to bulb B which is graduated and contains N₂ and have a tap to take out N₂.

* Measurement

- Bulb A is dipped in heat bath and bulb B and C are placed in melting ice bath.
- Due to heat there will be pressure difference between capillary end of and manometer will show deflection.
- A suitable amount of N₂ is taken out from bulb B to maintain pressure balance.

With the amount of Hg taken out we can calculate the temperature of bulb A on heat bath.

Calculation

Let; the volume of A = Volume of C = V

Volume of capillary cd = Volume of capillary of C = V_0

Volume of meniscus taken out = V'

Temperature of heat bath = T

Temperature of ice bath = T_0

Temperature of cd and Cd = T'

* The number of moles of gas = The number of mole of gas in bulb A + bulb B + Cd in bulb Cd

$$\Rightarrow \frac{PV}{RT} + \frac{PV_0}{RT'} + \frac{PV'}{RT_0} = \frac{PV}{RT_0} + \frac{PV_0}{RT'}$$

$$\Rightarrow \frac{V}{T} = \frac{V}{T_0} - \frac{V'}{T_0}$$

$$\Rightarrow T = \frac{V}{V-V'} T_0$$

Result

Adiabatic and diathermic walls

- * Adiabatic wall \Rightarrow Adiabatic wall is a wall which resists the flow of heat.
- * Diathermic wall \Rightarrow Diathermic wall is a wall which increase the flow of heat.

Thermal Expansion

- * Thermal Expansion \Rightarrow Thermal Expansion is the tendency of matter to change in volume in response to a change in temperature. All material have this tendency.

$$\alpha = \lim_{\Delta T \rightarrow 0} \frac{1}{L} \frac{\Delta L}{\Delta T}$$

Where, L = length of rod

$$\alpha = \frac{L_f - L_0}{L_0 \Delta T}$$

$$\Rightarrow L_f = L_0(1 + \alpha \Delta T)$$

$\Delta L/L = \text{Change in length}$
per unit temperature

L_0 = initial length

L_f = final length

ΔT = Temperature

α = coefficient of linear expansion

Similarly, $\{$ where, $y = \text{Coefficient of}$

$$V_\theta = V_0(1 + \gamma_0)$$

Volume expansion

- * Density of water is maximum at 4°C .
 - * Water at bottom of lake remains at 4°C in winter even if rest at the surface freezes.

→ This allows marine animals to remain alive and move near the bottom.

Worked Out Examples

- 1) The pressure of the gas in a constant volume gas thermometer at steam point (373.15K) is $1.50 \times 10^4 \text{ Pa}$. What will be the pressure at the triple point of water?

$$\text{Ans: } T = \frac{P_1 \times 273.16\text{K}}{P_{273}}$$

$$P_{273} = \frac{P \times 273.16\text{K}}{T} = \frac{1.5 \times 10^4 \times 273.16\text{K}}{273.15\text{K}}$$

$$P_{273} \approx 10^4 \text{ Pa}$$

- 2) The pressure of air in the bulb of a constant volume gas thermometer at 0°C and 100°C are 73cm and 100cm of Hg respectively. Calculate the pressure at room temperature.

$$\text{As } t = \frac{P_f - P_0}{P_{100} - P_0} \times 100^\circ\text{C}$$

$$20^\circ = \frac{P_f - 73}{100 - 73} \times 100^\circ$$

$$P_f = \frac{20(100 - 73)}{100} + 73 \Rightarrow 78.4 \text{ cm of Hg}$$

3) The pressure of the gas in a constant volume gas thermometer is 80 cm of Hg in melting ice at 0°C. When the bulb is placed in a liquid, the pressure becomes 160 cm of Hg. Find the temperature of the liquid.

$$\text{Ans} \quad \frac{T_1}{T_2} = \frac{P_1}{P_2} \Rightarrow \frac{273}{T_2} = \frac{80}{160}$$

$$T_2 = 2 \times 273 = 546 \text{ K}$$

ii) In a constant volume gas thermometer, the pressure of the working gas is measured by the difference in the levels of mercury in the two arms of a U-tube connected to the gas at one end. When the bulb is placed at the room temperature 27°C, the ~~the~~ mercury column in the arm open to atmosphere stands 5.00 cm above the level of mercury in the other arm. When the bulb is placed in a hot liquid, the difference of mercury levels becomes 15 cm. Calculate the temperature of the liquid. $1 \text{ atm} = 75 \text{ cm of Hg}$.

$$\text{Ans} \Rightarrow T_1 = (27 + 293) \text{ K} \quad \Delta P_1 = 5 \text{ cm Hg}$$

$$T_2 = ? \text{ K} \quad \Delta P_2 = 45 \text{ cm Hg}$$

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

$$\Rightarrow \frac{300}{T_2} = \frac{75+5}{45+75}$$

$$\Rightarrow T_2 = \frac{300 \times 120}{80} = 450 \text{ K}$$

$$T_2 = 179^\circ\text{C}$$

\Rightarrow The resistance of a platinum resistance thermometer at the ice point, the steam point and the boiling point of Sulphur are 2.50, 3.50 and 6.50 ohms respectively. Find the boiling point of Sulphur on the platinum scale. The ice point and the steam point measure 0° and 100° respectively.

$$\text{Ans} \Rightarrow \frac{t}{T} = R_t - R_0 \times \frac{1}{100} \Rightarrow \frac{6.5 - 2.5}{3.5 - 2.5} \times 100$$

$$t = 900^\circ\text{C}$$

Q) A platinum resistance thermometer reads 0° and 100° at the ice point and the boiling point of water respectively. The resistance of platinum wire varies with Celsius temperature θ as $R_t = R_0 (1 + \alpha \theta + \beta \theta^2)$, where $\alpha = 3.8 \times 10^{-3}/^\circ\text{C}$ and $\beta = -5.6 \times 10^{-7}/^\circ\text{C}^2$. What will be the reading of this thermometer if it is placed in a liquid bath maintained at 50°C ?

$$\text{Ans: } R_t = R_0 (1 + \alpha \theta + \beta \theta^2)$$

$$R_{50} = R_0 (1 + 50\alpha + 2500\beta)$$

$$R_{100} = R_0 (1 + 100\alpha + 10000\beta)$$

$$t = \frac{R_{50} - R_0}{R_{100} - R_0} \times 100$$

$$t = \frac{R_0 \{ 50\alpha + 2500\beta \}}{R_0 (100\alpha + 10000\beta)} \times 100$$

$$t = \frac{50 \times 3.8 \times 10^{-3} + 2500 \times (-5.6 \times 10^{-7})}{100 \times 3.8 \times 10^{-3} + 10000 \times (-5.6 \times 10^{-7})} \times 100$$

$$t = \frac{180 - 0.28}{7.6 - 0.112} = 50.7^\circ$$

7) A platinum resistance thermometer is constructed which reads 0° at ice point and 100° at steam point. Let t_p denote this temperature on his scale and let t denote the temperature on a mercury thermometer scale. The resistance of the platinum coil varies with t as $R_t = R_0(1 + \alpha t + \beta t^2)$. Derive an expression for the resistance as a function of t_p .

$$\text{Ans} \Rightarrow t_p = \frac{R_t - R_0}{R_{100} - R_0} \times 100$$

$$\Rightarrow R_t = \frac{t_p(R_{100} - R_0)}{100} + R_0$$

$$R_t = t_p R_0 \frac{100(\alpha + 100\beta)}{100} + R_0$$

$$R_t = R_0 \{ t_p(\alpha + 100\beta) + 1 \}$$

8) An iron rod of length 50 cm is joined at one end to ~~an~~ an ~~aluminum~~ aluminium rod of length 100 cm. All measurements refer to 20°C . Find the length of the

Composite system at 100°C and its average coefficient of linear expansion.
 The coefficient of linear expansion of iron and aluminium are $12 \times 10^{-6}/^{\circ}\text{C}$ and $24 \times 10^{-6}/^{\circ}\text{C}$ respectively.

$$\text{Ans} \rightarrow l_{Fe} \Rightarrow l_0 (1 + \alpha_0) \\ \Rightarrow 50 \times (1 + 12 \times 10^{-6} \times 80) \\ \Rightarrow 50 \times (1.6 \times 10^{-4} + 1) \\ \Rightarrow 50.048 \text{ cm}$$

$$l_{Al} \Rightarrow l_0 (1 + \alpha_0) \\ \Rightarrow 100 (1 + 24 \times 10^{-6} \times 80) \\ \Rightarrow 100.192 \text{ cm}$$

$$\text{length of composition} = 150.24 \text{ cm}$$

$$\Rightarrow \cancel{l} \times (1 + \alpha_0) = l_F - l \\ \Rightarrow \cancel{\alpha} l = l_F - l \\ \cancel{\alpha} = \frac{l_F - l}{l} = \frac{150.24 - 150}{80 \times 150} = \frac{0.24}{10 \cdot 12 \times 10^{-5}}$$

~~$$\alpha = 2 \times 10^{-5} / ^{\circ}\text{C}$$~~

Q) An iron ring, measuring 15.00 cm, in diameter is to be shrunk on a pulley which is 15.03 cm in diameter. All measurements refer to the room temperature 20°C . To what minimum temperature should the ring be heated to make the job possible? Calculate the strain developed in the ring when it comes to the room temperature. Coefficient of linear expansion of iron $= 12 \times 10^{-6}/^\circ\text{C}$

$$\text{Ans} \Rightarrow \alpha = 12 \times 10^{-6}/^\circ\text{C}$$

$$P_i = \pi d_1 = 15\pi$$

$$P_f = \pi d_2 = 15.03\pi$$

$$\rightarrow P_f = P_i (1 + \alpha \theta)$$

$$\Rightarrow \theta = \frac{P_f - P_i}{P_i \alpha} = \frac{0.03\pi}{15\pi \times 12 \times 10^{-6}}$$

$$\theta = 2.7 \times 10^{-4} \times 10^6$$

$$\theta = 277.7^\circ\text{C} \approx 278^\circ\text{C}$$

$$\text{Strain} = \frac{\Delta l}{l} = \frac{P_f - P_i}{P_i} = \frac{0.03\pi}{15\pi} = 3.3 \times 10^{-3}$$

$$\text{temperature} = 278^\circ\text{C}$$

10) A pendulum clock consists of an iron rod connected to a small, heavy bob. If it is designed to keep time at 20°C how fast or slow will it go in 24 hours at 40°C ? Coefficient of linear expansion of iron = $1.2 \times 10^{-5}/\text{oc}$.

$$\text{As } T = 2\pi \sqrt{l_0/g}$$

$$\Rightarrow 2\pi \sqrt{\frac{l_0(1+\alpha\Delta)}{g}}$$

$$\Rightarrow 2\pi \sqrt{l_0/g} \sqrt{1+\alpha\Delta} = T_0 \sqrt{1+\alpha\Delta}$$

$$T = T_0 \left\{ 1 + \frac{1}{2} \alpha \Delta \right\}$$

$$\frac{T_{40}}{T_{20}} = \frac{T_0 \left\{ 1 + \frac{1}{2} \cdot 70\alpha \right\}}{T_0 \left\{ 1 + \frac{1}{2} \cdot 20\alpha \right\}} = \frac{1 + 70\alpha}{1 + 20\alpha} \approx \frac{1 + 10\alpha}{1 + 10\alpha} = 1$$

$$T_{40} - T_{20} = 10\Delta = 1.2 \times 10^{-1}$$

~~DT₂₀~~ is proportional to ~~l₀~~ and ~~A~~ (SI units)

$$\Delta t = 24 \text{ hours} \times 1.2 \times 10^{-1}$$

$$\Rightarrow 10.48 \text{ sec of time at } 40^{\circ}\text{C}$$

~~but for given DT, Δt is constant~~ (original)

~~so $\Delta t = 24 \times 10.48 = 241.92 \text{ sec}$~~

~~so $\Delta t = 241.92 \text{ sec}$ is possible for 40°C but not for 20°C~~

1) A pendulum clock having copper rod keeps correct time at 20°C . It gains 15 second per day if cooled to 0°C . Calculate the coefficient of linear expansion of copper.

$$\text{Ans} \Rightarrow T = 2\pi \sqrt{l_0/g} \\ \approx T_0 (1 + \frac{1}{2}\alpha_0)$$

$$T_{20} \approx T_0 (1 + 10\alpha)$$

$$\frac{T_{20} - T_0}{T_0} = 10\alpha$$

$$\rightarrow \frac{T_{20} - T_0}{T_0} \times 24 \text{ hr} = 15 \text{ sec} \\ \alpha = \frac{0.15}{10 \times 24 \times 60 \times 60} = 1.7 \times 10^{-5} /{}^{\circ}\text{C}$$

12) A piece of metal weighs 46g in air and 30g in a liquid of density $1.2 \times 10^3 \text{ kg/m}^3$ kept at 27°C . When the temperature of the liquid is raised to 42°C , the metal piece weighs 30.5g. The density of the liquid at 42°C is $1.2 \times 10^3 \text{ kg/m}^3$. Calculate the coefficient of linear expansion of metal.

$$\text{Ans} \rightarrow m = 4.6 \times 10^{-3} \text{ kg}$$

V_0 = Volume of metal at 27°C

V_0' = Volume of metal at 42°C

ρ_0 = density of liquid at 27°C = $1.24 \times 10^3 \text{ kg/m}^3$

ρ_0' = density of liquid at 42°C = $1.2 \times 10^3 \text{ kg/m}^3$

m_0 = mass of liquid at 27°C = 30 g

m_0' = mass of liquid at 42°C = 30.5 g

$$\rho_0 V_0 = m - m_0$$

$$\rho_0 V_0 = m - m_0$$

$$\Rightarrow V_0 = \frac{\rho_0}{\rho_0} m - m_0$$

$$V_0 = \frac{\rho_0}{\rho_0} m - m_0$$

$$\Rightarrow \frac{V_0}{V_0} = \frac{\rho_0}{\rho_0} \times \frac{m - m_0}{m - m_0}$$

$$\Rightarrow (1 + 3\alpha) = \frac{\rho_0(m - m_0)}{\rho_0(m - m_0)} = 1 + 3\alpha = 1$$

$$\Rightarrow \alpha = \frac{\rho_0(m - m_0)}{3\rho_0(m - m_0)} - \frac{1}{50} = \frac{1.24 \times 10^3 \times 15 \times 10^{-3}}{3 \times 15 \times 1.2 \times 10^3 \times 16 \times 10^{-3}} - \frac{1}{50}$$

$$\alpha = 2.3 \times 10^{-5} / ^\circ\text{C}$$

13) A sphere of diameter 7 cm and mass 266.5 g floats in a bath of liquid. As the temperature is raised, the sphere begins to sink at a temperature of 35°C . If the density of the liquid is 1.527 g/cm^3 at 0°C , find the coefficient of cubical expansion of the liquid. Neglect the expansion of the sphere.

$$\text{Ans:- } d = 7 \times 10^{-2} \text{ m}$$

$$m = 0.2665 \text{ kg}$$

$$\theta = 35^\circ$$

$$\rho_0 = 1.527 \text{ g/cm}^3$$

γ = coefficient of cubical expansion

ρ_θ = density of liquid at θ

$$\rho_\theta = m/V = \frac{m}{V_0} \cdot 6m/\pi d^3 (1 + \gamma \theta)$$

$$\frac{V_0}{V_0 \cdot \rho_\theta} = \frac{\rho_0 \pi d^3}{6m} = 1 - \frac{1}{6m}$$

$$\Rightarrow 1 + \gamma \theta = \frac{\rho_0 \pi d^3}{6m}$$

$$\Rightarrow \gamma = \frac{\rho_0 \pi d^3}{6m \theta} = \frac{1}{\theta} = 8.2 \times 10^{-4}/^\circ\text{C}$$

2 Kinetic theory of gases

* Adeal gas \Rightarrow Gases which obeys equation $PV = nRT$ is called Adeal gas.

\Rightarrow Assumptions of Kinetic theory of Gases

- 1) All gases are made of molecules moving randomly in all directions.
- 2) The size of a molecule is much smaller than the average separation between the molecules.
- 3) The molecules exert no force on each other or on the walls of the container except during collision.
- 4) All collisions between two molecules or between a molecule and a wall are perfectly elastic. Also, the time spent during a collision is negligibly small.
- 5) The molecules obey Newton's laws of motion.
- 6) When a gas is left for sufficient time, it comes to a steady state. The density and the distribution of molecules with different velocities are independent of position direction and time.

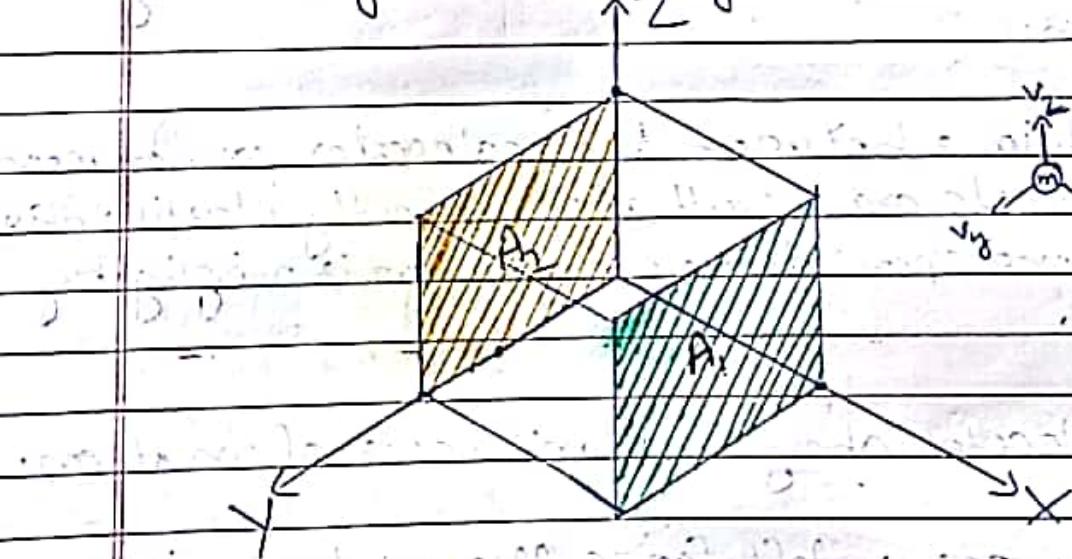
⇒ Calculation of the pressure of an ideal gas

* Consideration

→ Let us consider an ideal gas enclosed in a cubical vessel of edge L .

→ Let A_1, A_2 be the parallel faces \perp to X -axis.

→ Let us consider a molecule moving with velocity $\vec{v} = v_x \hat{i} + v_y \hat{j} + v_z \hat{k}$.



for large No
of molecules

⇒ When molecule collides with face A₁, V_x changes its direction and V_y and V_z remain the same

$$\Delta P = (-mv_x) - (mv_x) = -2mv_x$$

$$\Delta P \{ \text{wall} \} = 2mv_x \cdot S \text{ CLM}^{-1}$$

⇒ After rebound, this molecule travels toward A₂ with x-component of velocity equal to -V_x.

⇒ Time taken by the molecule to go from A₁ to A₂ = L/V_x

$$T \{ \text{Time period} \} = \frac{2L}{V_x}$$

$$\Delta F \{ \text{wall} \} = \frac{\Delta P}{\Delta t} = \frac{-2mv_x^2}{2L/V_x} = \frac{mv_x^2}{L}$$

$V_x^2 = V_y^2 = V_z^2$ {as all directions are symmetric}

$$V_x^2 = \frac{V_x^2 + V_y^2 + V_z^2}{3} = \frac{1}{3}V^2$$

$$F \{ \text{wall} \} = \frac{m}{3L} \sum v^2 \{ \text{Total force on wall A}_1 \}$$

$$P = \frac{Force}{Area} = \frac{m \cdot \sum v^2}{3L} = \frac{m \cdot \sum v^2}{3L^2} = \frac{m}{3L^2} \sum v^2$$

Let N be total no of molecules of gas in the given volume.

$$P = \frac{mN \sum v^2}{3L^2 N} = \frac{N \sum v^2}{3L^2} = \frac{N}{3} \sum v^2$$

$\left. \begin{array}{l} P = \frac{mN}{3L^2} = \text{density} \\ \text{Chene, } \frac{mN}{L^3} = \text{density} \\ \sum v^2 = \frac{\sum v^2}{N} = \text{mean square speed} \end{array} \right\}$

$$P = \frac{1}{3} \rho \bar{v}^2$$

* RMS Speed

→ The Square root of mean square speed is called root-mean speed or RMS speed.

→ It is denoted by the symbol v_{rms} .

$$v_{rms} = \sqrt{\frac{\sum v^2}{N}}$$

$$v_{rms}^2 = \frac{\sum v^2}{N}$$

$$P = \frac{1}{3} \rho V_{\text{rms}}^2$$

* Translational Kinetic Energy of gas

$$K = \sum m v^2 = \frac{1}{2} m N \sum v^2 = \frac{1}{2} M V_{\text{rms}}^2 = \frac{3}{2} P V$$

→ Average Kinetic Energy of a molecule

$$\frac{K}{N} = \frac{1}{2} \frac{M V_{\text{rms}}^2}{N} = \frac{1}{2} m v_{\text{rms}}^2$$

⇒ Kinetic interpretation of Temperature

→ Let P and V be the pressure of gas and the rms speed of the molecules at temperature T respectively.

→ Let P_0 & V_0 be the values of these quantities at temperature 273.16 K , keeping the volume same as that at temperature T .

$$PV = \frac{1}{3} M V^2 \quad / \quad P_0 V_0 = \frac{1}{3} M V_0^2$$

$$\Rightarrow \frac{P}{P_0} = \frac{V^2}{V_0^2} = T \quad / \quad PV = nRT$$

$$\Rightarrow T = \frac{273.16\text{ K} \cdot V^2}{V_0^2} = \left(\frac{546.32}{M V_0^2} \right) K \quad \left\{ \begin{array}{l} K = \text{Kinetic} \\ \text{Energy} \end{array} \right\}$$

$$\left. \begin{aligned} PV &= \frac{1}{3} m V_{\text{rms}}^2 \\ V_{\text{rms}}^2 &= \frac{V_o^2 T}{273+T} \end{aligned} \right\} \quad \begin{array}{l} \text{--- (I)} \\ \text{--- (II)} \end{array}$$

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$$\Rightarrow T \propto K$$

Thus, the absolute temperature of a given sample of gas is proportional to the total translational kinetic energy of its molecule.

Note

→ In thermal equilibrium, the average kinetic energy of all molecules are equal.

⇒ Deductions from Kinetic theory

(i) Boyle's law

At a given temperature, the pressure of a given mass of gas is inversely proportional to its volume.

$$P \propto \frac{1}{V} \text{ at } T = \text{Constant}$$

* Verification from kinetic theory of Gas

$$\Rightarrow V_{\text{rms}} \propto T \text{ from Eq (II)}$$

$$V_{\text{rms}} = \text{constant} \text{ for constant temperature}$$

$$\Rightarrow P \propto \frac{V^2}{V} \quad \left\{ \text{from Eqn ①} \right\}$$

$$\Rightarrow P \propto \frac{1}{V} \quad \left\{ \text{For Constant } V_{\text{rms}} \Rightarrow \text{for Constant } T \right\}$$

(ii) Charles law of Volume

At a given pressure, the volume of a given mass of a gas is proportional to its absolute temperature.

$$V \propto T \text{ at } P = \text{constant}$$

* Verification from KTG

$$V_{\text{rms}} \propto T \quad \left\{ \text{from Eqn ②} \right\} \quad ①$$

$$V \propto \frac{V_{\text{rms}}^2}{P} \quad \left\{ \text{from Eqn ①} \right\}$$

$$V \propto V_{\text{rms}} \quad \left\{ \text{For constant Pressure} \right\} \quad ②$$

Using ① and ② we get:

$$V \propto T \quad \left\{ \text{For constant Pressure} \right\}$$

(iii) Charles Law of pressure

At a given volume, the pressure of a given mass of a gas is proportional to its absolute temperature.

$$P \propto T \text{ at } V = \text{constant}$$

⇒ Verification of it using KTG is similar to that of Charles' law of volume-~~area~~.

(iv) Avogadro's Law

At same temperature and pressure, equal volume of all gases contains equal number of molecules.

*Verification from KTG

$$PV = \frac{1}{3} N_1 m_1 V_1^2 \quad \left\{ \text{from (1)} \right\}$$

$$PV = \frac{1}{3} N_2 m_2 V_2^2 \quad \left\{ \text{from (2)} \right\}$$

$$\Rightarrow N_1 m_1 V_1^2 = N_2 m_2 V_2^2 \quad \text{--- (4)}$$

$$\frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_2 v_2^2 \quad \left. \begin{array}{l} \text{at thermal} \\ \text{equilibrium} \end{array} \right\} \quad \text{(ii)}$$

Using (i) and (ii) we get :-

$$N_1 = N_2 \quad \left. \begin{array}{l} \text{which verifies Avogadro's law} \end{array} \right\}$$

(v) Graham's Law of Diffusion

When two gases at the same pressure and temperature are allowed to diffuse into each other, the rate of diffusion of each gas is inversely proportional to the square root of the density of the gas.

* Verification from KTG

rate of diffusion $\propto V_{rms}$ $\left. \begin{array}{l} \text{Assumption} \end{array} \right\}$

$$\frac{g_1}{g_2} = \frac{V_{1 rms}}{V_{2 rms}} \quad \text{(i)}$$

$$V_{rms} = \sqrt{\frac{3PV}{M}} \quad \text{(ii)}$$

Using (i) and (ii) we get :-

$$\frac{g_1}{g_2} = \sqrt{\frac{P_2}{P_1}} \quad \left. \begin{array}{l} \text{which is Graham's law} \end{array} \right\}$$

(VI) Dalton's Law of Partial Pressure

Dalton's law of partial pressure says that the pressure exerted by a mixture of several gases equals the sum of the pressures exerted by each gas occupying the same volume as that of the mixture.

* Verification from Kinetic Theory of Gas

Let us consider ~~as~~ different gasses in a container containing ~~of~~ molecules N_1, N_2, \dots

$$\text{Force on wall} = F_1 + F_2 + F_3 + \dots$$

$$P = P_1 + P_2 + P_3 + \dots$$

} which is Dalton's law of partial pressure

⇒ Ideal Gas Equations

$$PV = \frac{1}{3} N m v_o^2 \quad \text{--- (1)}$$

$$v_o^2 = \left(\frac{V_{tot}^2}{273.16K} \right) T \quad \text{--- (2)}$$

Using (1) and (2) we get

$$PV = N \left(\frac{1}{3} \frac{m v_o^2}{273.16K} \right) T$$

$\Rightarrow \frac{1}{2}mv_0^2 = \text{avg kinetic energy of a molecule}$
 at the triple point.

Avg Kinetic energy ~~of gas~~ for all the
 Gas at triple point is fixed, $\frac{1}{2}mv_0^2$ is a
 Universal constant.

$\Rightarrow \text{Let } K = \frac{1}{2}mv_0^2 = \text{constant.}$

$\left. \begin{array}{l} \\ \end{array} \right\} K \text{ is known as Boltzmann Constant}$

$$\Rightarrow PV = NKT$$

$$\Rightarrow \frac{N}{N_A} = n \text{ [mole]} \quad \left. \begin{array}{l} \\ N_A = 6.02 \times 10^{23} \text{ mol}^{-1} \end{array} \right\}$$

$$\Rightarrow PV = nN_A KT$$

$\left. \begin{array}{l} \\ \end{array} \right\} \text{Set, } R = N_A K = \text{constant} = \text{called Universal gas constant}$

$$\Rightarrow PV = nRT$$

$\left. \begin{array}{l} \\ \end{array} \right\} \text{This equation is known as ideal gas equation}$

* Rms Speed in terms of Temperature

$$PV = \frac{1}{3} Nm v^2 \quad \text{--- (i)}$$

$$PV = NkT \quad \text{--- (ii) Using object to gas}$$

// Using (i) and (ii) we get

$$v_0 = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3NkT}{mN}} = \sqrt{\frac{3RT}{M_0}}$$

M_0 = molecular weight

* Average kinetic Energy of molecules

$$KE_{\text{Avg}} = \frac{1}{2} m v_0^2 = \frac{1}{2} m \times \frac{3kT}{m} = \frac{3}{2} kT$$

$$\Rightarrow \text{Total Kinetic Energy} = \frac{3}{2} NkT = \frac{3}{2} nRT$$

$$\bar{v} = \sqrt{\frac{3RT}{m}}$$

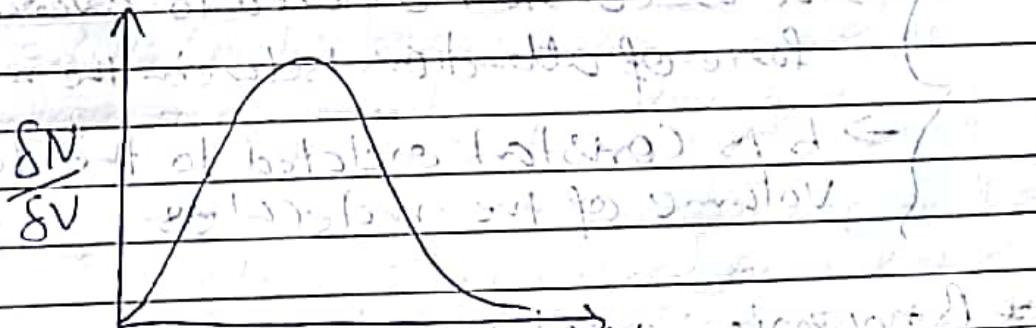
{without Proof}

⇒ Maxwell's Speed distribution law

→ In a gas at thermal equilibrium all its molecule does not move with same speed. Some move with greater ~~than~~ while some move with smaller speed than ~~than~~ rms.

→ Maxwell derived an expression giving the distribution of molecules in different speeds:

$$dN = \frac{4\pi N}{(2\pi kT)^{3/2}} \frac{m^{3/2}}{v^2} e^{-mv^2/2kT} dv$$



→ The Speed V_p at which dN/dv is maximum is called most probable speed.

$$V_p = \sqrt{\frac{2kT}{m}}$$

The thermodynamic State

→ Thermodynamic state of a given sample of an ideal gas is completely described if its pressure and its volume are given.

* Equation of State

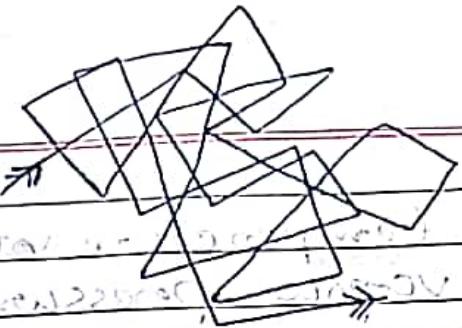
→ ~~Van der Waals~~ derived equation of state for a real gas

$$\left(P + \frac{a}{V^2} \right) (V - b) = nRT$$

- a is constant related to average force of attraction between the molecules
- b is constant related to the total volume of the molecules

* Brownian motion

Brownian motion is the apparently random motion of particles suspended in a fluid resulting from their collision by the fast moving atoms or molecules in the gas or liquid.



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Brownian motion

~~↳ Japan~~

\Rightarrow Vapour

- * Critical temperature \Rightarrow The Critical temperature of a substance is the temperature above which the substance cannot be liquefied; no matter how much pressure is applied.

- * Vapour \Rightarrow Vapour is a gas ~~below~~ bellow Critical temperature.

- * Evaporation \Rightarrow Evaporation is a process in which molecules escape slowly from the surface of a liquid.

- * Boiling \Rightarrow Boiling is the rapid vaporization of a liquid, which occurs when a liquid is heated to its boiling point, the temperature at ~~which~~ at which the vapor pressure of liquid is equal to the atmospheric pressure.

Temperature and

* Dew point \Rightarrow The temperature at which the saturation vapour pressure is equal to the present vapour pressure is called the dew point.

\Rightarrow Humidity (\leftarrow most important limiting factor of evaporation and condensation) \Rightarrow relative humidity

* Absolute humidity \Rightarrow The amount of water vapour present in a unit volume of air is called the absolute humidity of air.

* Relative humidity \doteq Limiting

(Amount of water vapour present in a given volume of air at a given temperature)

Amount of water vapour required to saturate the same volume of air at the same temperature

$\Rightarrow RH = \frac{\text{Vapour Pressure of air}}{\text{Saturation Vapour Pressure of air at that temperature}}$

SV Practice: Same temperature for condensation, out of liquid or liquid

Laws of Thermodynamics

⇒ First law of Thermodynamics

"Energy can neither be created nor be destroyed it can just be transformed from one form to another".

⇒ Suppose, in a process, an amount ΔQ of heat is given to the gas and an amount ΔW of work is done by it. Then $\Delta U = \Delta Q - \Delta W$

⇒ The total energy of the gas must increases by $(\Delta Q - \Delta W) \cdot A.0 = (Q) \cdot (A.0) = w_d$

⇒ If we denote the change in internal energy by ΔU , we get $\Delta U = \Delta Q - \Delta W$

$$\boxed{\Delta U = \Delta Q - \Delta W}$$

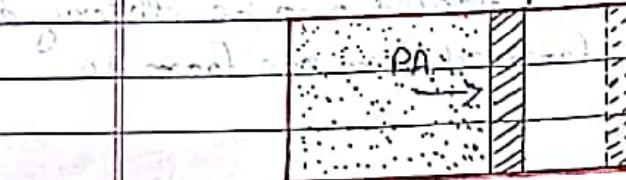
Fundamental equation of
first law of Thermodynamics

*Convention

⇒ If work is done by the system, then its positive & if work is done on the system then its negative.

⇒ When heat is given to the system, then its positive & if it is given by the system then its negative.

\Rightarrow Work done by a gas

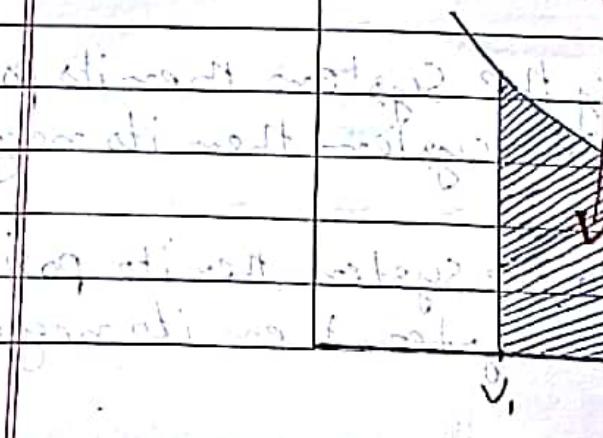


i) Consider a gas contained in a cylinder of cross-sectional area A fitted with a movable piston.

$$\Delta W = \int (P_A) \cdot (dx) = \int P(A dx) \quad (A = \text{constant})$$

$$\Delta W = \int P \cdot dV$$

P_1



* Work done on an ideal gas

(1) Isothermal Process {Temperature Constant}

$$PV = nRT \quad \{ \text{Ideal gas equation} \}$$

$$P = \frac{nRT}{V} \quad \{ \text{For P is constant} \}$$

$$dP = \frac{nRdT}{V^2} \quad \{ \text{For V is constant} \}$$

$$\Delta P = \frac{nR\Delta T}{V^2} \quad \{ \text{For V is constant} \}$$

$$W = \int_{V_1}^{V_2} P \cdot dV = \int_{V_1}^{V_2} \frac{nRT}{V} dV = nRT \ln \left| \frac{V_2}{V_1} \right|$$

(2) Isobaric Process {Pressure Constant}

$$W = \int_{V_1}^{V_2} P \cdot dV = P(V_2 - V_1)$$

(3) Isochoric Process {Volume Constant}

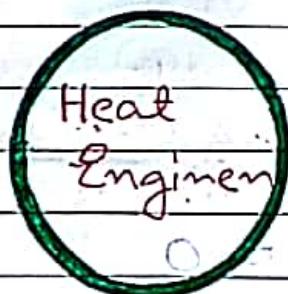
$$W = \int_{V_1}^{V_2} P \cdot dV = P \times 0 = 0$$

Heat Engines

- ⇒ Heat Engines are devices which converts heat energy into mechanical work.
- ⇒ It takes some heat from bodies at higher temperature, converts a part of it into the mechanical work and delivers the rest to bodies at lower temperature.

High-Temperature Body

Heat $\downarrow Q_1$ $= v h \cdot q^1 = W$



Heat $\downarrow Q_2$

Low-Temperature Body

Work $= v h \cdot q^2 = W$

* Efficiency $\{\eta\}$ = $\frac{\text{Work done by the engine}}{\text{heat supplied to it}}$

$$\eta = \frac{\Delta W}{Q_1} \quad \text{--- (i)}$$

$$\Delta U = \Delta W + \Delta Q$$

$\Delta W + (Q_2 - Q_1) = 0$. [As there is no change in Internal energy]

$$\Delta W = Q_1 - Q_2 \quad \text{--- (ii)}$$

Using (i) & (ii) we get :-

$$\eta = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} \rightarrow \text{here - note (i)}$$

* Some Commonly used engines

Engines

External Combustion
Engines

Internal Combustion
Engines

Steam
Engine

Petrol
Engine

Diesel
Engine

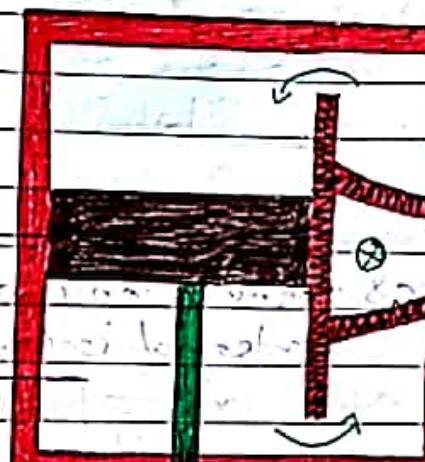
①

②

③

① STEAM ENGINE

Condense Water
going damage
to the boiler



Steam Chest

D-Valve

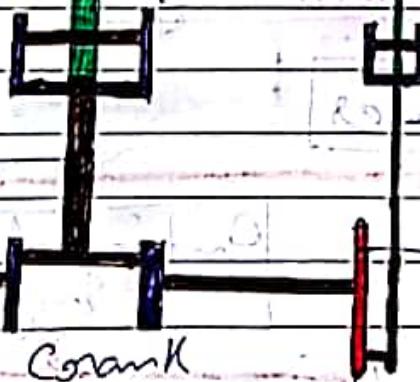
Valve - rod

Piston

Main
Cylinder

Piston-rod

Crank-rod



Eccentric-rod

Eccentric link rod

fly wheel

Shaft

② Petrol Engine (4-Stroke)

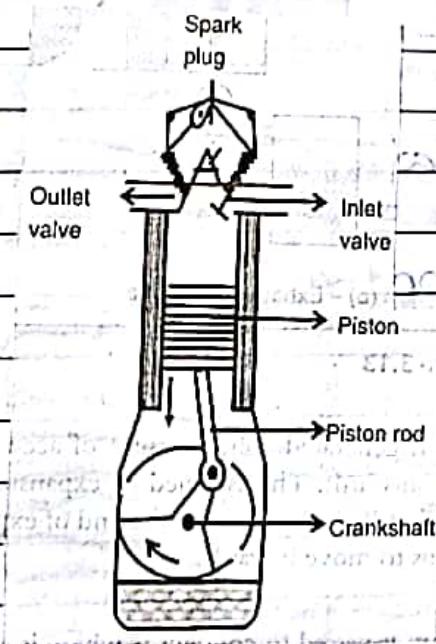
1. Charging Stroke

2. Compression Stroke

3. Working Stroke

4. Exhaust Stroke

* Carburettor \Rightarrow A carburettor is a device that blends air & fuel for an internal combustion engine.



Second Law of Thermodynamics

"It is not possible to have a process in which the entropy of an isolated system is decreased."

* Reversible processes

- Quasi-Static process \Rightarrow It is an idealised process in which all changes take place infinitely slowly.
- A process can be reversible if it satisfies two conditions :-

(i) Quasi-static

(ii) nondissipative

* Entropy \Rightarrow Entropy is the measure of disorder.

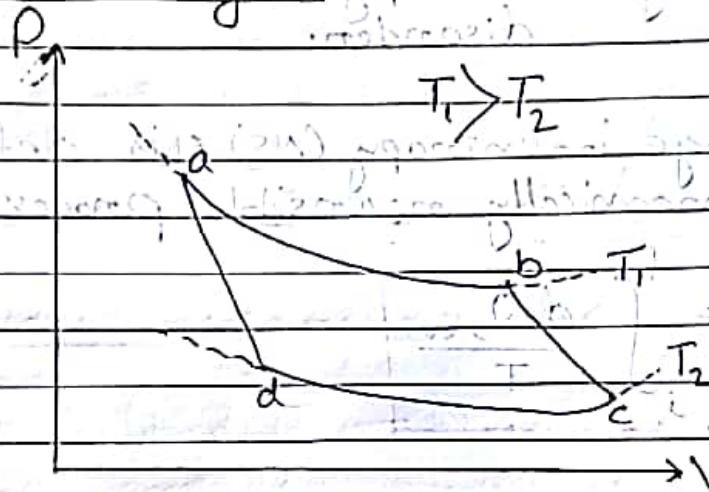
\Rightarrow The change in entropy (ΔS) is defined for a thermodynamically irreversible process as \dagger :

$$\Delta S = \int_i^f \frac{dQ_{\text{rev}}}{T}$$

\rightarrow Entropy is not a conserved quantity.

\rightarrow Entropy can be created but cannot be destroyed \ddagger $\text{as it is arrangement in}$

\Rightarrow Cannot Engine



* Initial State \Rightarrow Cylinder with ideal gas, Kept in contact with the high temperature body at temperature T_1 , in compressed state.

1) $(a-b)$ \Rightarrow Gas is isothermally expanded to a state 'b' during which gas does work on system and heat (Q_1) is supplied to it by external source

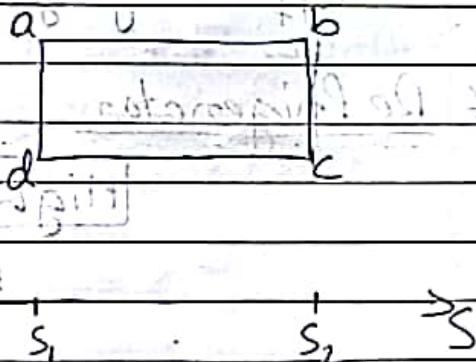
2) $(b-c)$ \Rightarrow Gas is adiabatically expanded to state 'c' which is at lower temperature T_2 . During which gas does some work.

3) (c-d) \Rightarrow Gas is isothermally compressed to state 'd' during which work is done on the gas & gas rejects some heat (Q_2) into the external source.

4) (d-a) \Rightarrow Gas is adiabatically compressed to state 'a' which is at higher temperature T_1 . During which work is done on the gas.

* Efficiency of a Carnot Engine (n)

\Rightarrow The basic process of a Carnot engine can be shown by (Temperature-entropy) diagram.



$$S_2 - S_1 \quad (a \rightarrow b) = \frac{Q_1}{T_1} - \textcircled{I}$$

$$S_1 - S_2 \quad (c \rightarrow d) = \frac{-Q_2}{T_2} - \textcircled{II}$$

Using eq. I & II we get $\frac{Q_1}{T_1} = \frac{-Q_2}{T_2}$

$$\frac{Q_1}{T_1} = \frac{Q_2}{T_2}$$

$$\Rightarrow \eta = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

such that $Q_1 > Q_2$

$$\Rightarrow \eta = 1 - \frac{T_2}{T_1}$$

* Carnot's Theorem

"All reversible engines operating between the same two temperatures have equal efficiency and no engine operating between the same two temperatures can have an efficiency greater than this"

* Refrigerator

High-Temperature Body

Heat $\uparrow Q_1$



Work $\leftarrow W$

Heat $\uparrow Q_2$

Low-Temperature Body

\Rightarrow It is not possible to design a refrigerator which works in cyclic process and whose only result is to transfer heat from a body to a hotter body. {Clausius statement}

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Calorimetry

- * Calorie \Rightarrow The amount of heat needed to increase the temperature of 1g of water from 14.5°C to 15.5°C at a pressure of 1 atm is called 1 calorie.

- * Principle of calorimetry \Rightarrow The principle of calorimetry states that the total heat given by hot object equals the total heat received by the cold object.

- * Specific heat capacity \Rightarrow Specific heat capacity of a substance is defined as the heat supplied per unit mass of the substance per unit rise in the temperature.

$$S = \frac{\Delta Q}{m \Delta T}$$

$$V\delta q + U\beta = 0$$

- * Molar heat capacity \Rightarrow Molar heat capacity of a gas is defined as the heat given per mole of the gas per unit rise in the temperature.

$$C = \frac{\Delta Q}{n \Delta T}$$

$$\text{①} - 0 = V\delta q + TB_v \Delta n$$

$$TB_v \Delta n = Vq \text{ lashi i } \Delta n$$

Adiabatic processes

A process in which no heat is supplied to or extracted from it is called adiabatic.

Relation between P and V

Let's consider a diabatic process in which no heat is supplied or extracted.

Let during a short part of the process

$$(P, V, T) \rightarrow (P + \delta P, V + \delta V, T + \delta T)$$

Let internal energy change from:

$$U \rightarrow U + \delta U$$

Total heat supplied = 0

~~Q~~ ~~ΔT~~

$$0 = \delta U + P\delta V \quad \left. \begin{array}{l} \text{From First Law of} \\ \text{Thermodynamics} \end{array} \right\}$$

$$C_V = \frac{1}{n} \frac{dQ}{dT} = \frac{1}{n} \frac{dU}{dT} \quad \left. \begin{array}{l} Q = U \\ \text{if } \Delta V = 0 \end{array} \right\}$$

$$dU = nC_V dT$$

$$nC_V dT + P\delta V = 0 \quad \text{--- (1)}$$

as gas is ideal $PV = nRT$

$$PdV + VdP = nRdT \quad \text{--- (1)}$$

$$PdV + VdP = \frac{n}{\gamma} R \left(-P\gamma V \right) + \left(T \frac{\partial \gamma}{\partial T} \right) V \frac{dV}{V}$$

$$\left(P + \frac{RP}{C_V} \right) \delta V + V \delta P = 0 \quad \text{--- (2)}$$

$$P \left(1 + \frac{R}{C_V} \right) \delta V + V \delta P = 0$$

$$P \left(C_V + R \right) \delta V + V \delta P = 0$$

$$P \left(\frac{C_P}{C_V} \right) \delta V + V \delta P = 0 \quad \left[\because C_P - C_V = R \right]$$

$$\Rightarrow \gamma \frac{dV}{V} = - \frac{dP}{P} \quad \left[\frac{C_P}{C_V} = \gamma \right]$$

$$\Rightarrow \gamma \ln \left| \frac{V_f}{V_i} \right| = - \ln \left| \frac{P_f}{P_i} \right| \quad \left[\frac{1}{V} = \frac{1}{V_i} - \frac{1}{V_f} \right] = \frac{q}{T_f} - \frac{q}{T_i}$$

$$\frac{V_f}{V_i} = \frac{P_i}{P_f} \Rightarrow P_i V_i^{\gamma} = P_f V_f^{\gamma} \quad \left[\frac{V_f}{V_i} = \frac{T_f}{T_i} \right]$$

$$\Rightarrow \text{Hence } P V^{\gamma} = \text{constant}$$

$$\boxed{P V^{\gamma} = \text{constant}}$$

$$V_f = V_i \left(\frac{T_f}{T_i} \right)^{\frac{1}{\gamma}} = V_i \left(\frac{T_f}{T_i} \right)^{\frac{1}{\gamma}}$$

Relation between TP & T $T = \frac{P}{V} + \frac{nR}{m} V$

$$\frac{P(mC_V dT)}{P} + V \cancel{\delta P} = mRdT = \cancel{mRdT} + V \cancel{\delta P}$$

$$V \cancel{\delta P} = (mR + mC_V) dT \quad \left\{ \begin{array}{l} \cancel{m} \\ \cancel{R} \\ \cancel{C_V} \end{array} \right.$$

$$\frac{\gamma RT \cancel{\delta P}}{P} = \gamma \left(R + C_V \right) \cancel{\delta T} \quad \left\{ \begin{array}{l} \cancel{R} \\ \cancel{C_V} \end{array} \right.$$

~~$$\frac{\cancel{\delta P}}{P} = \frac{\cancel{\delta T}}{T} = \frac{R}{C_V}$$~~

~~$$\frac{\cancel{\delta T}}{ST} = \frac{P - ST - R - \cancel{SF}}{ST} = \frac{V \cancel{\delta P}}{V} = \frac{V}{V}$$~~

$$\frac{T}{ST} - \frac{P}{ST} = \frac{T}{ST} - \frac{R}{C_V} \times \frac{1}{ST} = \frac{T}{ST} \left\{ \frac{1}{Y} \right\}$$

$$\frac{T}{ST} \left\{ \frac{1}{Y-1} \right\} = \frac{P}{ST}$$

$$Y \frac{ST}{P} = \left\{ \frac{ST}{P} (Y-1) \right\}$$

$$T_1 \frac{P_1^Y}{P_1^{1-Y}} = T_2 \frac{P_2^Y}{P_2^{1-Y}}$$

$$T_1^Y P_1^{1-Y} = T_2^Y P_2^{1-Y}$$

$$\Rightarrow P^Y \times T^Y = \text{Constant}$$

Relation between V & T

$$\therefore PV^Y = \text{Constant}$$

$$mRTV^{Y-1} = \text{constant}$$

$$\therefore TV^{Y-1} = \text{constant}$$

// Work done in adiabatic process

$$W = \int P \cdot dV = \int K \frac{dV}{V^{Y-1}} = K \left[\frac{1}{Y-1} \left(\frac{1}{V_2} - \frac{1}{V_1} \right) \right]$$

$$P_1 = \frac{K}{V_1^{Y-1}} \quad kP_2 = \frac{K}{V_2^{Y-1}} \quad \therefore \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\frac{1}{Y-1}}$$

$$\text{So, } W = \frac{1}{Y-1} [P_2 V_2 - P_1 V_1]$$

$$W = \frac{P_1 V_1 - P_2 V_2}{Y-1}$$

Equipartition of Energy

* degree of freedom \Rightarrow The number of independent parameters in the expression of energy of a molecule is called its degree of freedom.

\Rightarrow Equipartition of energy states that the average energy of a molecule in a gas associated with each degree of freedom is $\frac{1}{2} kT$.

$\therefore U = \frac{1}{2} kT \times 3N_A = Vb \cdot gT = L$
 So for monoatomic gas:

$$U = n N_A \left(\frac{3}{2} kT \right)$$

$$U = \frac{3n}{2} RT$$

$$C_V = \frac{1}{n} \frac{dU}{dT} = \frac{1}{n} \frac{3nR}{2} = \frac{3R}{2} = \frac{xR}{2}$$

$$C_P = C_V + R = \frac{5R}{2} = \frac{x+2}{2} R$$

$$\gamma = \frac{C_P}{C_V} = \frac{5}{2} = 1.67 \quad \gamma = \frac{x+2}{x} = 1 + \frac{2}{x}$$

Gases	X	degree of freedom
① Monatomic gas	3	
② Diatomic with no vibration	5	
③ Diatomic with vibration	7	
④ Polyatomic	8	

⇒ To define the molar heat capacity of a gas the process should be specified :-

(i) Molar heat capacity at (C_V)

Constant volume

(ii) Molar heat capacity (C_p)

at constant pressure

$$C_p - C_V = R \quad \{ \text{for ideal gas} \}$$

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Heat Transfer

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⇒ Heat can be transferred from one place to another by three different methods, namely, conduction, convection and radiation.

- ① Conduction ⇒ Transfer of energy between objects that are in physical contact.
- ② Convection ⇒ Transfer of energy between an object and its environment due to fluid motion.
- ③ Radiation ⇒ The transfer of energy from the movement of charged particle within atoms is converted to Electromagnetic radiation.

Thermal Conductivity {Fourier's Law}

"Time rate of heat transfer through a material is proportional to the negative gradient in the temperature and the area at right angle to the temperature gradient through which the heat flow"

$$\frac{dQ}{dt} = -KA \frac{dT}{dx}$$

} for linear heat flow

where K is constant for material
called its thermal conductivity

$$\frac{\Delta Q}{\Delta t} = -KA \frac{\Delta T}{\Delta x} \quad \{ \text{integral form} \}$$

Electro static analogy } Only at steady state

$$\text{Let } Q(\text{Heat}) = Q(\text{charge})$$

$$T(\text{Temperature}) = V_{\bullet}(\text{potential})$$

$$-\nabla T = \vec{E}_{\bullet}(\text{Field})$$

$$\frac{(\text{Thermal})}{(\text{conductivity})} K = \sigma_{\bullet} (\text{conductivity})$$

$$\frac{1}{K} = f(\text{Resistivity})$$

$$\frac{I}{|A|} \frac{dQ}{dt} \hat{n} = \vec{J} (\text{current density})$$

$$\frac{dQ}{dt} = i (\text{current})$$

$$R = f \frac{l}{A}, V = IR, Q = it = \int i \cdot dt$$

$$\vec{J} = \sigma \vec{E} \quad \{ \text{all electrostatic relations} \}$$

etc...

Radiation

→ Kirchhoff's Law

→ Nature of thermal radiation [Wien's displacement Law]

→ ~~Stefan-Boltzmann Law~~

$$(Emissivity) = \sigma T^4$$

$$(Emissivity)_{abs} = (Emitted) T^4$$

$$(Emitted) = T^4$$

$$(Emitted) = \epsilon (Emitted)$$

$$(Emitted) = \frac{1}{\epsilon}$$

$$(Emitted) = \frac{\epsilon \sigma T^4}{\epsilon}$$

$$(Emitted) = \frac{\sigma T^4}{\epsilon}$$

$$\epsilon = 1 \Rightarrow T = V$$

For black body radiation $\epsilon = 1$ $\Rightarrow T = V$

$$\epsilon = 1 \Rightarrow T = V$$

* Working with real gas

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① Van der waals Equation

Vander waal pointed out following faulty assumptions in Kinetic theory of gases & derived equation for real gas.

- ① Space occupied by a gas molecule is negligible when compared with average space present for a molecule.
- ② Intermolecular attraction is negligibly small in gasses.

* Volume Correction of Van der waals

Van der waal assumed that molecule of a real gas are rigid spherical particle which possess a definite volume.

⇒ Volume available for compression or movement is there for "actual volume" minus the volume occupied by gas molecules.

$$V_i = (V - nb)$$

Where b is a constant associated with gas, which describes effective volume of gas per mole.

* Pressure Correction

Real gas molecules do not collide with the wall of container with same momentum as expected from ideal gas equation. This is due to inter molecular attraction between molecules of gases.

$$P_i = P_0 + P^I$$

where, P^I is

Pressure correction

// Pressure correction depends of two factors :-

(1) The attractive force exerted on a single molecule about to strike the wall is proportional to the number of molecules per unit volume in the bulk of the gas.

(2) The number of molecules striking the wall which is also proportional to the number of molecules per unit volume of the gas.

$$P^I \propto d^2 \propto \frac{n^2}{V^2}$$

$$\therefore P^I = \frac{an^2}{V^2}$$

$$\Rightarrow P_i = P_0 + \frac{an^2}{V^2} \quad \text{--- (5)}$$

Relating $P + \frac{an^2}{V^2}$ & $V - nb$ with ideal gas equation we get:

$$\left(P + \frac{an^2}{V^2} \right) (V - nb) = nRT$$

{ Real gas }
{ deviation }

② Boyle temperature

The temperature at which real gas behave like ideal gas and obeys the gas law is called Boyle temperature.

$$T_b = \frac{a}{Rb}$$

{ without verification }

③ Compressibility factor (Z) = $\frac{\text{Molar volume of Real gas}}{\text{Molar volume of ideal gas}}$

$$Z = \frac{PV}{nRT}$$

{ definition }

* $Z = 1$ for ideal gas { can not be liquified }

$Z \neq 1$ for real gas

$Z > 1$

→ Positive deviation

→ Repulsive force are dominant

→ Less compressible

$Z < 1$

→ Negative deviation

→ Attractive force are dominant

→ More compressible

⑨ Critical Temperature \Rightarrow Critical temperature of a gas is temperature above which the gas cannot be liquified, no matter how much pressure is applied.

$$T_c = \frac{8a}{27Rb}$$

{Without Verification}

* Critical Pressure \Rightarrow Min. Pressure to liquify gas at Critical temperature.

$$P_c = \frac{a}{27b^2}$$

{Without Verification}

* Critical Volume \Rightarrow Volume of 1 mole of gas at Critical temperature & pressure.

$$V_c = 3b$$

{Without Verification}

