15 MOLECULAR THEORY OF GASES

HEAT:

DEFINITION:

Energy in transit from a hot body to a cold body due to their temperature difference, when they are in thermal contact, is called HEAT.

Units:

SI Unit:

Heat is a form of energy, thus its SI unit is JOULE(J).

1 J = 1 N.m

CGS UNIT:

The CGS unit is **Calorie (cal).**

1 cal = 4.18J

FPS unit:

The FPS unit is **BRITISH THERMAL UNIT (Btu).**

1 Btu = 1055 J = 252 cal

DEFINITION OF CALORIE:

"The quantity of heat required to raise the temperature of 1 gm of water by 1 C° (from 14.5 °C to 15.5 °C) at standard pressure is called 1 CALORIE"

DEFINITION OF BRITISH THERMAL UNIT:

"The quantity of heat required to raise temperature of 1 lb (or $\frac{1}{32}$ slug) of water by 1 F° (from 63 °F to 64 °F) at standard pressure is called 1 Btu."

HOT BODY:

A body with more internal energy and high temperature is called s HOT BODY

COLD BODY

A body with less internal energy and low temperature is called a COLD BODY

THERMAL CONTACT:

DEFINITION:

"If heat can flow between two bodies, whether they are in physical contact or not, they are said to be in THERMAL CONTACT.

TEMPERATURE:

DEFINITION:

"The physical property which determines the quantity and direction of heat flow between two bodies in thermal contact is called TEMPERATURE. It is a measure of the average Kinetic energy of molecules of a substance."

THERMAL EQUILIBRIUM:

When a hot body is brought in thermal contact with a cold body, heat starts flowing from hot to cold body due to their temperature difference. As a result of heat transfer, the internal energy and temperature of hot body fall. The transferred heat energy becomes the internal energy heat energy becomes the internal energy of the cold body thus its internal energy and temperature increase.

The stage during heat transfer at which the internal energies and temperatures of the two bodies become equal is called THERMAL EQUILIBRIUM; no heat transfer takes place thereafter.

INTERNAL ENERGY:

DEFINITION:

"The sum of all the microscopic energies of molecules of a thermodynamic system, including the intermolecular potential energy and the molecular kinetic energy (translational KE, rotational KE & vibrational KE), is called internal energy of the system."

It is a characteristic property of the state of the system

MATHEMATICAL FROM:

The total energy of a single molecule is given as:

$$E = K_T + K_R + K_V + PE$$

INTERNAL ENERGY OF MONATOMIC GASES:

In monatomic gases, the molecules have transitional motion only and no rotational or vibrational motion thus they have only translational KE. In addition, there are no forces of attraction between the molecules, thus their PE is zero. This implies that:

$$E = K_T \qquad [k_R = 0,\ k_v = 0\ ,\ PE = 0]$$

And $U = K_{T1} + K_{T2} + K_{T3} + ...$

INTERNAL ENERGY OF POLYATOMIC GASES:

In polyatomic gases, the molecules have all three types of motion, thus they have translation, rotational and vibrational kinetic energies. There also exist forces of attraction between these molecules, due to which they also possess PE. Thus,

$$E = K_T + K_R + K_V + PE$$

And $U = E_1 + E_2 + E_3 + ...$

THERMOMETRIC PROPERTIES.

DEFINITION:

"The properties of a substance which change uniformly with change in temperature are called THERMOMETRIC PROPERTIES and such substances are called THERMOMETRIC SUBSTANCE.

Examples:

Length, Volume, Colour, Pressure, Resistance, Resistivity, etc.

SCALES OF TEMPERATURE

Fixed points or Reference points:

"While calibrating a thermometer, two easily reproducible reference temperatures are selected which called the fixed points or the REFERENCE POINTS."

1. **ICE POINT:**

   "The temperature of mixture of ice and water in equilibrium at 1 atm pressure is called ICE POINT"

   It is the lower fixed point. It is taken as **0** °C or **32** °F.

2. **STEAM POINT**

   "The temperature at which pure water boils into steam at 1 atm pressure is called STEAM POINT"

   It is the upper fixed point. It is taken as **100** °C or **212** °F.

1) **CELSIUS SCALE:**
   - The scale was named after its inventor **ANDERS CELSIUS**.
   - The ice point is taken as **0°C**.
   - The steam point is taken as **100 °C.**
   - The interval between ice and steam points is divided into **100** equal division.
   - Each division is called **DEGREE CELSIUS,** denoted as **°C**.
   - The lowest possible temperature is **-273°C.**

- The normal temperature of human body is **37°C**.

2) FAHRENHEIT SCALE:

- The scale was named after its inventor **DANIEL FAHRENHEIT**.
- The ice point is taken as **32°F**.
- The steam point is taken as **212°C.**
- The interval between ice and steam points is divided into **180** equal division.
- Each division is called **DEGREE FAHRENHEIT,** denoted as **°F**.
- The lowest possible temperature is **-460°F.**
- The normal temperature of human body is **98.6 °F**.
- The scale is no longer used for scientific purposes.

3) KELVIN SCALE:

- A British scientist **Lord kelvin** devised a thermodynamic temperature scale called the **KELVIN SCALE** or **ABSOLUTE SCALE**, on which is **ABSOLUTE ZERO** taken as **0. K**.
- Negative values of temperature are not allowed in Kelvin scale.
- The scale uses only one fixed point, called **TRIPLE POINT OF WATER** (**273.16 k** or **0.01 °C**)
- The ice point is at **273 K**.
- The steam point is at **373 K**.
- There are **100** division between ice point and steam point.
- The normal temperature of human body is **310 k**.

ABSOLUTE ZERO

"The theoretically lowest possible temperature (-273 °C or -460 °F) at which the motion of an ideal gas molecules ceases to exist, and the volume and pressure of the ideal gas becomes zero is called absolute zero."

	ABSOLUTE ZERO	ICE POINT	STEAM POINT
CELSIUS	-273 °C	0 °C	100 °C
FAHRENHEIT	-460 °F	32 °F	212 °F
KELVIN	0 K	273 K	373 K

QUANTITATIVE RELATIONS

A general relation between the scales can be obtained by equating the following equation for each scale:

$$\frac{\left(\begin{array}{c}\text{Temperature on}\\ \text{the Scale}\end{array}\right) - \left(\begin{array}{c}\text{Ice point on}\\ \text{the Scale}\end{array}\right)}{\left(\begin{array}{c}\text{No. of Divisions}\\ \text{on the Scale}\end{array}\right)}$$

Thus, $$\frac{T_c - 0}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273}{100}$$

RELATIONSHIP BETWEEN CELSIUS AND FAHRENHEIT SCALES:

Equation ① can be rewritten as:

$$\Rightarrow \frac{T_c}{100} = \frac{T_F - 32}{180}$$

$$\Rightarrow T_c = \frac{\text{[illegible]}}{\text{[illegible]}}(T_F - 32)$$

$$\Rightarrow \boxed{T_c = \frac{5}{9}(T_F - 32)}$$

$$\Rightarrow \frac{5}{9}T_c = T_F - 32$$

$$\Rightarrow \boxed{T_F = \left(\frac{9}{5}T_c\right) + 32}$$

$$\Rightarrow \boxed{T_F = (1.8\,T_c) + 32}$$

RELATIONSHIP BETWEEN CELSIUS AND KELVIN SCALES:

Equation ① can be rewritten as:

$$\frac{T_c}{100} = \frac{T_F - 273}{100}$$

$$\Rightarrow T_c = T_k - 273$$

OR $\boxed{T_c = T_k + 273}$

NOTE:

Units for Temperature (T)		Units for Temperature (ΔT)	
Kelvin Degree Celsius Degree Fahrenheit	K °C °F	Kelvin Celsius Degree Fahrenheit Degree	K °C °F
$T_c = \frac{5}{9}(T_F - 32)$		$\Delta T_c = \frac{5}{9}\Delta T_f$	
$T_F = (1.8\,T_c) + 32$		$\Delta T_F = 1.8\,\Delta T_c$	
$T_c = T_F - 273$		$\Delta T_K = \Delta T_c$	

GAS LAWS

DEFINITION:

"The state of a gas can be described by four variables viz. pressure, volume, temperature and mass(no. of moles), called STATE VARIABLES. Any relation between two state variables at least keeping other constant, is called a GAS LAW or a GAS EQUATION."

BOYLES'S LAW OR PV-LAW

INTRODUCTION:

This law was propounded by **ROBERT BOYLE** in **1660**. It describes the relation between volume and pressure of a fixed mass of a gas at constant temperature.

STATEMENT:

"The pressure of a fixed mass of a gas is inversely proportional to the Gas volume, provided temperature is kept constant."

Or

"The product of pressure and volume of a fixed mass of a gas always Remains constant provided temperature is kept constant."

MATHEMATICAL EXPRESSIONS:

According to Boyle's law, for a fixed mass of a gas

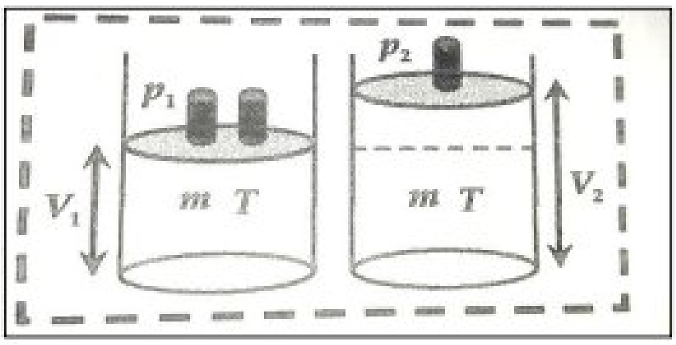
$p \propto \frac{1}{V}$ (At const T)

In equation from, p = (constant) $\frac{1}{V}$

OR $\boxed{PV = \text{Constant}}$ (At const T)

EXPRESSION FOR TWO STATES:

We consider a gas enclosed in a system. The pressure on the system is decreased from P_1 to P_2 keeping temperature constant at T. consequently, the volume of the gas increase from V_1 to V_2.



For initial state, $P_1 V_1 = \text{constant}$

For initial state, $P_2 V_2 = \text{constant}$

Thus, for **Two** states of a fixed mass of a gas:

$$P_1 V_1 = P_2 V_2$$

EXPRESSION FOR 'n' STATES:

For 'n' states of a fixed mass of a gas,

$$P_1 V_1 = P_2 V_2 = P_3 V_3 = \ldots = P_n V_n \qquad \text{(At Const } T\text{)}$$

BOYLE'S LAW FOR VARIABLE MASS:

Experiments show that increasing the mass of a gas directly affects its pressure i.e.

$$p \propto m$$

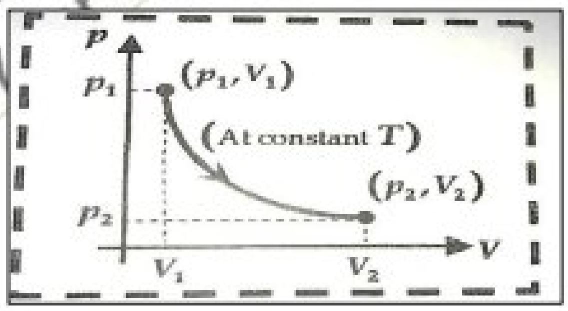
And Boyle's Law gives $\quad p \propto \frac{1}{V} \qquad$ (At const T)

Combining, $\quad p \propto \frac{m}{V} \qquad$ (At const T)

OR $\quad \frac{pV}{m} = \text{constant} \qquad$ (At const T)

For **Two** states of variable mass of a gas,

$$\frac{p_1 V_1}{m_1} = \frac{p_2 V_2}{m_2} \qquad \text{(At const } T\text{)}$$



GRAPH:

At constant temperature, the graph between pressure and volume is a **hyperbolic curve** showing inverse relationship between the two.

CHARLES' LAW

INTRODUCTION:

This law waspropoundedby **JACQUES CHARLES** in 1787. It describes the relation between volume and absolute temperature of a fixed mass of a gas at constant pressure.

STATEMENT:

"The volume of a fixed mass of a gas is directly proportional to its absolute temperature, provided pressure is kept constant

Or

The ratio of volume and absolute temperature of a fixed mass of a gas always remains constant, provided pressure is kept constant

MATHEMATICAL EXPRESSIONS:

According to Charles' Law

$$V \propto T \qquad \text{(At const } P\text{)}$$

In equation from, $\quad V = (\text{Constant})\, T$

OR $\frac{V}{T}$ = constant (At const P)

EXPRESSION FOR TWO STATE:

We consider a gas enclosed in a system. The absolute temperature of the system is increased from T_1 to T_2, keeping pressure constant at P. Consequently the volume of the gas increases from V_1 to V_2

For initial state, $\frac{V_1}{T_1}$= constant

For initial state, $\frac{V_2}{T_2}$= constant

Thus, for two states of a fixed mass of a gas:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$ (At const P)

EXPRESSION FOR 'n' STATES:

For 'n' states of a fixed mass of gas,

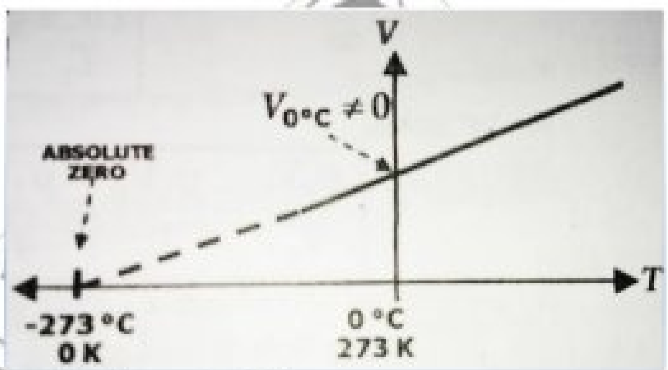
$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3} = \ldots = \frac{V_n}{T_n}$$ (At const P)

GRAPH:

At constant pressure, the graph between temperature and volume is a **STRAIGHT LINE** which should pass through the origin to ascertain the direct, relationship between V and T.

To resolve this discrepancy we extra-plot this volume-Temperature curve downwards until it intercepts the temperature axis at **-273°C** indicating a **ZERO VOLUME.**

Thus -273°C is the theoretically lowest possible temperature, called **ABSOLUTE ZERO** and is designated**ZERO KELVIN(0 K).**



ABSOLUTE ZERO

"The theoretically lowest possible temperature (-273°C or -460°F) at which the motion of an ideal gas molecules ceases to exist and the volume and pressure of the ideal gas become zero is called ABSOLUTE ZERO"

The line cannot be extended further, because negative volume is a meaningless notion.

GENERAL GAS EQUATION OR IDEAL GAS EQUATION

Introduction:

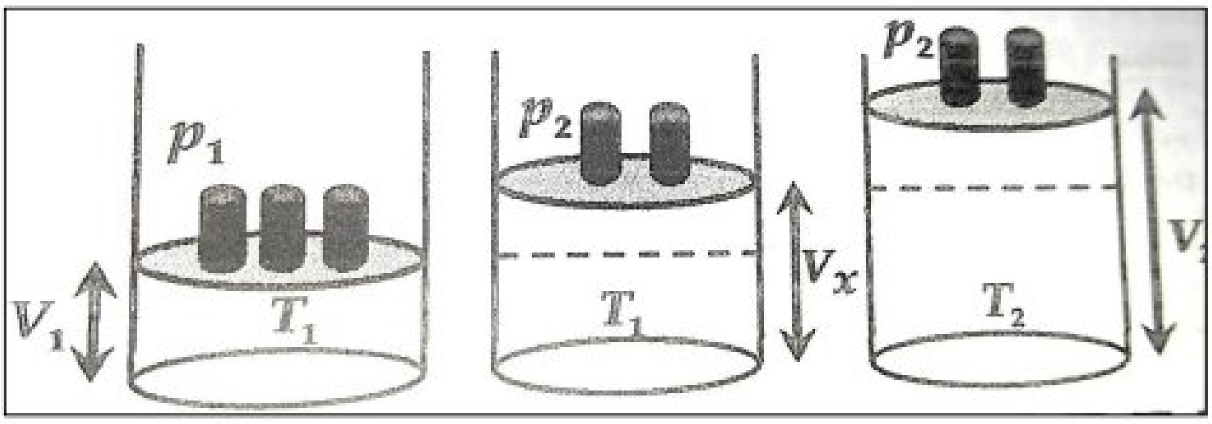
The mathematical equation relating the state variables of a gas viz, pressure volume temperature and mass (no. of mole) is called **IDEAL GAS EQUATION** or **GENERAL GAS EQUATION** or **EQUATION OF STATE**.

Mathematical Derivation:

We consider a piston-cylinder system in which fixed mass of an ideal gas is enclosed. The gas is initially at pressure P_1,absolute temperature T_1, and its volume is V_1.If the pressure of the gas is decreased from P_1 to P_2 keeping absolute temperature constant at T_1, the volume of the gas increases from V_1 to V_x applying Boyle's law for fixed mass:

$$P_1 V_1 = P_2 V_x$$

$$V_x = \frac{p_1 V_1}{p_2} \qquad \text{------①}$$



Now the absolute temperature of the gas increased from T_1 to T_2 keeping pressure constant at P_2; the volume of the gas increases from V_x V_2 applying Charles' law for fixed mass:

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

$$V_x = \frac{V_2 T_1}{T_2} \qquad \text{-----②}$$

Comparing eqn ① and eqn ②,we get.

$$\frac{p_2 V_1}{p_2} = \frac{V_2 T_1}{T_2}$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

For 'n' states,

$$\boxed{\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} = \frac{p_3 V_3}{T_3} = \ldots = \frac{p_n V_n}{T_n}}$$

For single state of fixed mass of a given gas, the above equation will becomes:

$$\boxed{\frac{pV}{T} = \text{Constant}}$$

The above constant can be evaluated if we know the pressure, volume and absolute temperature however, this constant is of no significance as its value changes as soon as the nature of the gas or its no. of particles is changed.

Thus, we calculate the value of this constant for 1 mole of a gas, as 1 mole of every gas contains equal o of particles (**Avogadro's No. = N_A = 6.02 x 10^{23}**) and has equal volume (**Molar volume = 22.4 dm^3**). This molar constant is called **UNIVERSAL GAS CONSTANT (R)**. Its value in SI is **R= 8.314** $\frac{J}{mol.K}$.

For 1 mole of any gas, we rewrite the above equation as:

$$\frac{pV}{T} = R$$

$$\boxed{PV = RT}$$

For 2 moles,

$$PV = 2RT$$

for 'n' moles of any gas

$$\boxed{PV = nRT}$$

The relation is **GENERAL GAS EQUATION** or **EQUATION OR STATE.**

KINETIC-MOLECULAR THEORY OF GASES

OR

KINETIC-MOLECULAR MODEL OF AN IDEAL GAS

INTRODUCTION:

The kinetic-molecular model provides the basic understanding of the macroscopic properties of a gas in terms of its molecular structure and behavior. It was first proposed by **Hermann in 1738**, and was improved later on by **Bernoulli, Maxwell, Boltzmann. Gibbs and Helmholtz.**

DEFINITION:

The theory which considers gas as made up of point molecules constantly in translational motion and applies laws of mechanics to this motion is called KINETIC-MOLECULAR THEORY (KMT) of gases.

BASIC ASSUMPTIONS:

1) **COMPOSITION OF GASES:**
A gas enclosed in a container consisted of a very large number of identical particles called molecules each molecules has same mass under stable conditions.
2) **POINT-MASS BEHAVIOR:**
The gas molecules behave as point particles, i.e their size is negligibly small as compared to the distances between the molecules and the size of the container.
3) **VOLUME OCCUPAIED BY GAS MOLECULES:**
The volume occupied by the gas molecules is negligible as compared to the total volume of the gas, i.e a finite volume of a gas contains very large number of molecules (At STP, there are approximately 3×10^{25} per m^3 of a gas.
4) **RANDOM TRANSLATIONAL MOTION AND COLLUSIONS:**
The molecules move randomly along straight lines, until they collide with one other or with the walls of the container.
5) **ELASTIC COLLISIONS:**
The collisions between molecules or between wall and molecules are perfectly elastic.
6) **NO INTERMOLECULAR FORCE:**
Molecules exert no forces on each other except during collisions, thus they move in straight lines.
7) **APPLICABILITY OF NEWTONIAN LAWS:**
Newton's laws of mechanics are applicable to the motion of the molecules.
8) **CONTAINER WALLS:**
The container walls are perfectly rigid and infinitely massive and do not move during collisions.
9) **GASEOUS PRESSURE:**
The gas pressure is due to the force excreted by the gas molecules on the container during molecule-walls collisions.
10) **TIME OF COLLISION:**
The time of collision is negligible in comparison to the time taken by the molecules to travel from one molecule to another.

KINETIC INTERPRATION OF GAS PRESSSURE

EXPRESSION FOR "PRESSURE"

We consider N molecules of an ideal gas, each of mass m, enclosed in a cubical container of edge length l. if every molecules is moving with velocity v then the components of velocity will be v_x, v_y and v_z.

We consider a molecule which starts its motion from the wall $\mathbf{A_1}$ of the cube along + x-**axis**. It is obvious that it does not have y or z components of velocity, and its net velocity is v_x. it strikes the wall $\mathbf{A_2}$ and rebounds back with a velocity $-v_x$.

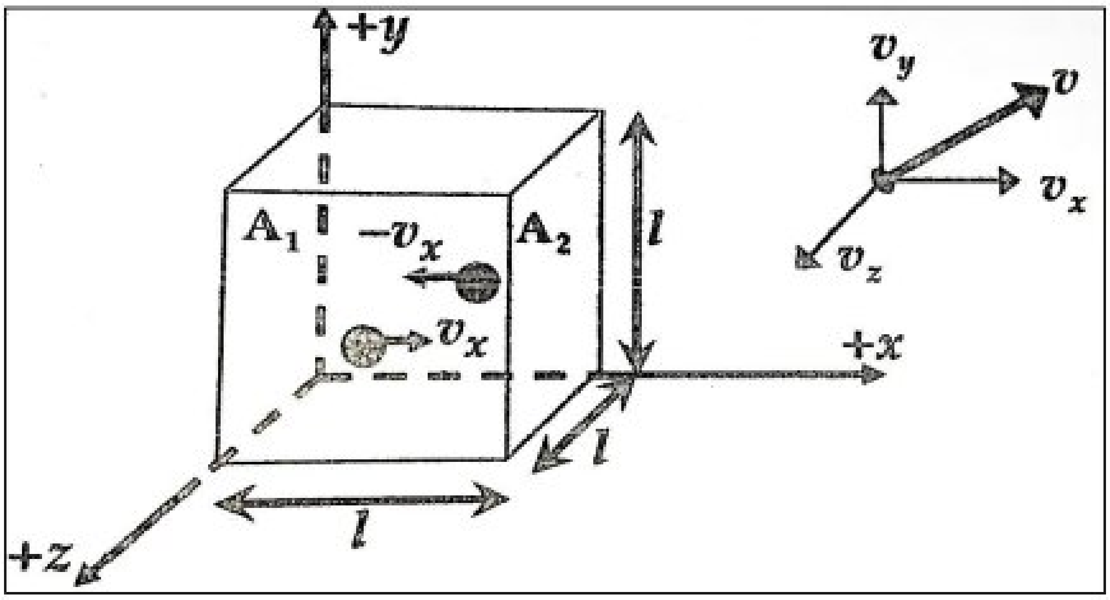
Momentum of molecule before collision: $P_i = mv_x$

Momentum of molecule after collision $P_f = m(-v_x) = -mv_x$

Thus, change of momentum of molecule: $\Delta P = P_f - P_i$

$= (-mv_x) - (mv_x)$

$\Delta P = -2\,mv_x$



For one collision we can relate distance and speed as:

$$\mathbf{v} = \frac{s}{t}$$

$$\mathbf{t} = \frac{s}{v}$$

$$\mathbf{t} = \frac{2l}{v_x}$$

According to newton's 2nd law of Motion,

$$F_{\text{on body}} = \frac{\Delta P_{\text{body}}}{t}$$

$$F_{\text{W on M}} = \frac{\Delta P_{\text{Molecule}}}{t}$$

$$F_{\text{W on M}} = \frac{-2mv_x}{2l/V_x} = \frac{-mv^2{}_x}{l}$$

According to Newton's Third Law,

$$F_A = -F_R$$

$$F_{M\ on\ W} = -F_{W\ on\ M}$$

$$F_{M\ on\ W} = -\left(\frac{-mv^2{}_x}{l}\right)$$

$$\boxed{F_{\text{[redacted]}} = \frac{\text{[redacted]}^2{}_x}{l}}$$

The total force exerted by all molecules on the wall moving along + x-axis will be

We are using capital P for momentum and small p for pressure.

$$F_{total} = \frac{mv^2{}_{1x}}{l} + \frac{mv^2{}_{2x}}{l} + \ldots + \frac{mv^2{}_{Nx}}{l}$$

$$F_{total} = \frac{m}{l}\left(v^2{}_{1x} + v^2{}_{2x} + \ldots + v^2{}_{Nx}\right) \quad \text{------}①$$

The gas pressure is given as:

$$\text{Gas pressure} = \frac{\text{Total Force (by molecules on wall)}}{\text{Area of wall}}$$

$$P = \frac{\frac{m}{l}\left(v^2{}_{1x}+v^2{}_{2x} + \ldots + v^2{}_{Nx}\right)}{l^2}$$

$$P = \frac{m\left(v^2{}_{1x}+v^2{}_{2x} + \ldots + v^2{}_{Nx}\right)}{l^3} \quad \text{------}②$$

Now, we consider a new variable 'No. of molecules per unit volume' Nv i.e

$$\rho = \frac{m}{V} = \frac{mN}{l^3}$$

$$\frac{\rho}{N} = \frac{m}{l^3}$$

$$P = \frac{m(v^2{}_{1x} + v^2{}_{2x} + \ldots + v^2{}_{Nx})}{l^3}$$

Now,eoh②

$$P = \rho\left(\frac{v^2{}_{1x} + v^2{}_{2x} + \ldots + v^2{}_{Nx}}{N}\right) \qquad ----③$$

Here $\left(\frac{v^2{}_{1x} + v^2{}_{2x} + \ldots + v^2{}_{Nx}}{N}\right) = \overline{v^2{}_x} = \left(\begin{matrix}\textit{Mean square velocity of} \\ \textit{Molecules in } x - \textit{direction}\end{matrix}\right)$

Thus, eqn③ $P = \rho\overline{V^2{}_x}$ ____________(4

The mean square velocity of gas molecules can be expressed in 3-dimensions as:

$$\overline{v^2} = \overline{v^2{}_x} + \overline{v^2{}_y} + \overline{v^2{}_z}$$

In stable state, $\overline{v^2{}_x} + \overline{v^2{}_y} + \overline{v^2{}_z}$

$$\overline{v^2} = \overline{v^2{}_x} + \overline{v^2{}_x} + \overline{v^2{}_x}$$

$$\overline{v^2} = 3\overline{v^2{}_x}$$

$$\overline{v^2{}_x} = \frac{1}{3}\overline{v^2}$$

Thus eqn 4 becomes $\boxed{P = \frac{1}{3}\rho\overline{v^2}}$

We can rewrite the above equation as

$$P = \left(\frac{1}{3}\rho\right)\overline{v^2} == (\text{Constant})\overline{v^2}$$

$$\boxed{P \propto \overline{v^2}}$$

EXPRESSION FOR MEAN SQUARE SPEED

We know that $P = \frac{1}{3}\rho\overline{v^2}$

$\overline{v^2}$ [redacted] $\frac{3p}{p}$

EXPRESSION FOR ROOT MEAN SQUARE SPEED

We know that $P = \frac{1}{3}\rho\overline{v^2}$

$$\overline{v^2} = \frac{3p}{p}$$

$$\sqrt{\overline{v^2}} = \sqrt{\frac{3p}{p}}$$

v [redacted] $\sqrt{\frac{3p}{p}}$

Here $\sqrt{\overline{v^2}} = V_{RMS}$ represent **ROOT MEAN SQUARE SPEED** of molecules.

KINETIC INTERPRETATION OF GAS TEMPERATURE

EXPRESSION FOR TEMPERATURE &AVERAGE TRANSLATIONAL KINETIC ENERGY

We know that

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

$$P = \frac{1}{3}m\frac{N}{V}\overline{v^2} \qquad [\because \rho = m\frac{N}{V}]$$

$$PV = \frac{1}{3}m\,N\overline{v^2} \qquad [\because \rho V = nRT]$$

$$nRT = \frac{1}{3}m\,N\overline{v^2}$$

$$3RT = m\frac{N}{n}\overline{v^2} \qquad [\text{Note that } \sqrt{\overline{v^2}} = v_{RMS} \neq \overline{v} \neq v]$$

We can write:

$$nN_A = N$$

$$N_A = \frac{N}{n}$$

$$3RT = m\,N_A\overline{v^2}$$

$$\frac{3RT}{N_A} = m\,\overline{v^2}$$

$$m\,\overline{v^2} = 3\frac{R}{N_A}\,T$$

Here the ration $\frac{R}{N_A} = K$ is called **BOLTZMANN CONSTANT**.

Its SI value is $k = 1.38\text{x}10^{-23}\frac{J}{K}$

Thus, we get

$$m\,\overline{v^2} = 3kT$$

$$\boxed{\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT}$$

$$\boxed{\text{ATKE} = \frac{3}{2}kT}$$

This is the expression for **average translational kinetic energy** of a gas Molecule.
We can rewrite the above equation as

$$\text{ATKE} = \left(\frac{3}{2}k\right)T = (\text{constant})\ T$$

$$\boxed{\text{ATKE} \propto T}$$

Thus, the average translational kinetic energy of a gas molecule is directly proportional to the absolute temperature of the gas.

Expression FOR MEAN SQUARE SPEED:

We know that

Note that $k = \dfrac{8.314\frac{J}{mol\,K}}{6.023\text{ x}10^{23}\frac{molecule}{mol}} = 1.38 \text{ x } 10^{-23}\dfrac{J}{molecule\,K}$

$$\frac{1}{2}m\,\overline{v^2} = \frac{3}{2}kT$$

$$\boxed{\overline{v^2} = \frac{3kT}{m}}$$

We can rewrite above eqn as

$$\overline{v^2} = \left(\frac{3k}{m}\right)T = (\text{constant})\ T$$

$$\boxed{\overline{v^2} \propto T}$$

EXPRESSION FOR ROOT MEAN SQUARE SPEED:

We know that

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT$$

$$\overline{v^2} = \frac{3kT}{m}$$

$$\sqrt{\overline{v^2}} = \sqrt{\frac{3kT}{m}}$$

$$\boxed{v_{RMS} = \sqrt{\frac{3kT}{m}}}$$

Here $\sqrt{\overline{v^2}}$ v_{RMS} Represent **ROOT MEAN SQUARE SPEED** of molecules.

KINETIC INTERPRETATION OF CHARLES'LAW

We know that

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

$$P = \frac{1}{3}m\frac{N}{V}\overline{v^2} \qquad [\because \rho = m\frac{N}{V}]$$

$$PV = \frac{1}{3}m\,N\overline{v^2}$$

$$PV = \frac{1}{3}\,N(m\,\overline{v^2})$$

$$PV = \frac{1}{3}\,N\left(\frac{1}{2}m\,\overline{v^2}\right) \times 2$$

$$PV = \frac{2}{3}\,N\left(\frac{3}{2}kT\right) \qquad [\because \frac{1}{2}m\,\overline{v^2} = \frac{3}{2}kT]$$

$$PV = NkT$$

$$\frac{V}{T} = \frac{Nk}{P}$$

We examine the RHS of the above equation, and infer that:

(1) '*k*' is Boltzmann constant.

(2) Total no. of gas molecules '*N*' will be constant for fixed mass of a gas.

(3) The pressure '*p*' has to be made constant itself.

If mass is fixed and pressure is kept constant, the whole RHS will becomes a constant.

Thus for a fixed mass of a gas, we can write

$$\boxed{\frac{V}{T} = \text{constant}}$$

The charles' Law is verified on the basis of kinetic-Molecular Theory.

KINETIC INTERPRETATION OF BOYLE'S LAW

$$p = \frac{1}{3}\rho\overline{v^2}$$

$$p = \frac{1}{3}mN_V\overline{v^2} \qquad [\because \rho = mN_V]$$

$$p = \frac{1}{3}m\frac{N}{V}\overline{v^2} \qquad [\because \rho = m\frac{N}{V}]$$

$$PV = \frac{1}{3}m\,N\overline{v^2}$$

We examine the RHS of the above equation, and infer that:

(1) The mass of a gas molecule 'm' for a particular gas is constant.

(2) Total no. of gas molecules 'N' will be constant for fixed mass of a gas.

(3) The mean square speed $\overline{v^2}$ depends directly upon Absolute Temperature, i.e $\overline{v^2} \propto T$. if T is kept constant $\overline{v^2}$ will also remain constant.

If mass is fixed and pressure is kept constant, the whole RHS will become a constant.
This for a fixed mass of a gas, we can write

$$\boxed{PV = \text{Constant}} \qquad \text{(At constant } T\text{)}$$

The Boyle's Law is verified on the basis of kinetic-Molecular Theory.

Prove That: P= $N_V\, kT$

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

$$P = \frac{1}{3}\rho\,\overline{v^2} \qquad [\because \rho = mN_V]$$

$$P = \frac{1}{3}mN_V\overline{v^2}$$

$$P = \frac{1}{3}N_V\left(m\,\overline{v^2}\right)$$

$$P = \frac{1}{3}\,N\left(\frac{1}{2}m\,\overline{v^2}\right) \times 2$$

$$P = \frac{2}{3}N_V\left(\frac{3}{2}kT\right) \qquad [\because \frac{1}{2}m\,\overline{v^2} = \frac{3}{2}kT]$$

$$\boxed{P = N_V\,kT}$$

16 FIRST LAW OF THERMODYNAMICS

THERMODYNAMICS

DEFINITION:

"The study of relationship among heat, work and other forms of energy, and the methods for their transformation, is called THERMODYNAMICS".

THERMODYNAMICS' TERMINOLOGY

1. SYSTEM:

"A collection of matter that has distinct and well-defined boundaries is called a SYSTEM."

Or

Any real or imaginary portion of the universe which is under consideration is called SYSTEM."

TYPES OF SYSTEM:

a) Open System:

"A system in which both matter and energy can be transferred between the system and the surroundings, is called OPEN SYSTEM.

Example: Hot water in a glass

b) CLOSED SYSTEM:

"A system in which energy can be transferred between the system and the surroundings, but mass cannot be transferred, is called CLOSED SYSTEM.

Example: (i) food in a pressure cooker

(ii) Gas enclosed in a piston-cylinder system with conducting base

c) ISOLATED SYSTEM:

"A system in which neither energy nor mass can be transferred between the system and the surrounding, is called ISOLATED SYSTEM

Examples: Tea in a thermos flask.

2. Surroundings:

"Any thing outside the system in the universe is called SURROUNDINGS or ENVIRONMENT of the system."

The system and its surroundings together constitute the whole universe

HEAT CAPACITY

Definition:

"Amount of heat required to raise the temperature of any mass of a substance by unit temperature (1 K) is called HEAT CAPACITY"

MATHEMATICAL EXPRESSION:

For any mass of a substance, the amount of heat is directly proportional to change in temperature i.e

$$Q \propto \Delta T$$

$$\boxed{Q = C'\Delta T}$$

In equation form,

Thus proportionality constant C' is called **HEAT CAPACITY**

it is a **material constant**.

Heat capacity may be expressed as

$$\boxed{C' = \frac{Q}{\text{[illegible]}}}$$

UNITS:

SI Unit: $\frac{J}{k} = \frac{J}{^\circ c}$

OTHER Units: $\frac{J}{^\circ F}, \frac{cal}{^\circ c}, \frac{Btu}{^\circ F}$, etc.

SPECIFIC HEAT CAPACITY

Definition:

"Amount of heat required to raise the temperature of unit mass of a substance by unit temperature (1 K) is called SPECIFIC HEAT CAPACITY"

MATHEMATICAL EXPRESSION:

For a substance, the amount of heat is directly proportional to mass as well as change in temperature, i.e

$$Q \propto m$$

& $$Q \propto \Delta T$$

Combining, $$Q \propto m\Delta T$$

In equation form, $$\boxed{Q = cm\Delta T}$$

The proportionality constant *C* is called specific **HEAT CAPACITY**.

It is a **material constant**

$$\boxed{c = \frac{Q}{m\Delta T}}$$

SI Unit: $\frac{J}{kg.K} = \frac{J}{kg.^\circ c}$

OTHER Units: $\frac{J}{g.K} = \frac{J}{g.^\circ c}, \frac{cal}{g.^\circ c}, \frac{Btu}{lb.^\circ F}$, etc.

RELATION BETWEEN HEAT CAPACITY AND SPECIFIC HEAT:

The heat capacity of a substance is given by

$$\boxed{C' = \frac{Q}{\Delta T}} \quad \text{----①}$$

The specific heat of a substance is given by

$$\boxed{c = \frac{Q}{m\Delta T}} \quad \text{----②}$$

Dividing eqn ①by eqn ②, we have

$$\frac{c}{C'} = \frac{Q}{m\Delta T} \div \frac{Q}{\Delta T} = \frac{Q}{m\Delta T} \times \frac{\Delta T}{Q}$$

$$\frac{c}{c'} = \frac{1}{m}$$

$$\boxed{C' = m \times c}$$

i.e (Heat Capacity) = (Mass) x $\begin{pmatrix}\text{Specific}\\ \text{Heat}\end{pmatrix}$

MOLAR SPECIFIC HEAT

DEFINITION:

"Amount of heat required to raise the temperature of 1 mole of a substance by unit temperature (1 K) is called MOLAR SPECIFIC HEAT.

Mathematically:

For any mass of a substance, the amount of heat is directly proportional to the molar mass (no. of moles) as well as the change in temperature i.e

$$Q \propto n$$

& $$Q \propto \Delta T$$

Combining, $$Q \propto n\,\Delta T$$

In equation form, $Q = Cn\,\Delta T$

The proportionality constant C is called **MOLAR SPECIFICHEAT CAPACITY**.

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

SI Unit: $\frac{J}{mol.K} = \frac{J}{mol.C^{\circ}}$

OTHER Units: $\frac{J}{mol.K} = \frac{cal}{mol.C^{\circ}}, \frac{J}{mol.K}, \frac{kcal}{mol.C^{\circ}}$, etc.

RELATION BETWEEN SPECIFIC HEAT AND MOLAR SPECIFICHEAT:

The heat of a substance is given by

$$c = \frac{Q}{m\Delta T} \quad \text{----①}$$

The molar specific heat is given by

$$C = \frac{Q}{n\Delta T} \quad \text{----②}$$

Dividing eqn ② by eqn①, we have

$$\frac{C}{c} = \frac{Q}{n\Delta T} \div \frac{Q}{m\Delta T}$$

$$\frac{C}{c} = \frac{Q}{n\Delta T} \div \frac{m\Delta T}{Q}$$

$$\frac{C}{c} = \frac{m}{n}$$

The no of moles of a substance is given by

$$n = \frac{m}{M} \quad \text{(where } M \text{ = Molecular Mass)}$$

$$M = \frac{m}{n}$$

Thus, we have

$$\frac{C}{c} = M$$

$$C = M \times c$$

i.e $\left(\text{Molar Specific Heat}\right) = \left(\text{Molecular Mass}\right) \times \left(\text{Specific Heat}\right)$

MOLAR SPECIFIC HEATS OF GASES

MOLAR SPECIFIC HEAT AT CONSTANT PRESSURE 'C_P'

DEFINITION:

"Amount of heat required to raise the temperature of 1 mole of a gas at constant pressure by unit temperature (1 K) is known as MOLAR SPECIFIC HEAT AT CONSTANT PRESSURE.

MATHEMATICAL EXPRESSION:

$$Q_p = nC_p\,\Delta T$$

$$C_p = \frac{Q_p}{n\Delta T}$$

MOLAR SPECIFIC HEAT AT CONSTANT VOLUME 'C_V':

DEFINITION:

"Amount of heat required to raise the temperature of 1 mole of a gas at constant volume by unit temperature (1 K) is known as MOLAR SPECIFIC HEAT AT CONSTANT VOLUME.

MATHEMATICAL EXPRESSION:

$$Q_V = nc_V\,\Delta T$$

$$C_V = \frac{Q_V}{n\Delta T}$$

EXPLANATION: (REASON FOR TWO MOLAR SPECIFIC HEATS FOR GASES)

We generally consider two molar specific heats for gases, as the temperature of a gas can be increased in two ways:

(1) HEATING AT CONSTANT PRESSURE (ISOBARIC PROCESS):

If heat is supplied to a gas at constant pressure the temperature of the gas increases, there by producing a proportionate increase in the gas volume. This is in accordance with **CHARLES' LAW**

i.e $\quad V \propto T \quad$ (At constant P)

In an isobaric process, the heat Q_p supplied to the system is utilized in:

1. Increasing the internal energy of the system
2. Producing work during the process

Thus, we have molar specific heat of a gas at constant pressure 'C_p'

(2) HEATING AT CONSTANT VOLUME (ISOCHORIC PROCESS)

If a gas is heated at constant volume the temperature of the gas increase, there by producing a proportionate increase in the gas pressure. This is in accordance with **CHARLES' PRESSURE LAW.**

i.e $\quad P \propto T \quad$ (At constant P)

in an isochoric process, the heat Q_V supplied to the system is utilized in:

1. Increasing the internal energy of the system (As no work is produced in the process.

Thus, we have molar specific heat of a gas at constant volume 'C_V'.

SPECIFIC LATENT HEAT

DEFINITION:

"Amount of heat required to change the state of unit mass of a substance without changing its temperature is called SPECIFIC LATENT HEAT or SPECIFIC HEAT OF TRANSFORMATION.

$$Q \propto m$$

In equation $\quad Q = mL$

The proportionality constant L is called **SPECIFIC LATENT HEAT**

It is a **material constant**.

The specific latent heat may be expressed as

$$L = \frac{Q}{m}$$

UNITS:

SI Unit: $\frac{J}{kg}$

OTHER Units: $\frac{J}{g}, \frac{cal}{g}, \frac{Btu}{lb.}$, etc.

SPECIFIC LATENT HEAT OF FUSION: L_F:

"Amount of heat required to change unit mass of a solid to liquid state at the melting point without change in temperature is called SPECIFIC LATENT HEAT OF FUSION.

$$(L_f)_{Water} = 336\frac{J}{g} = 336{,}000\frac{J}{kg}$$

SPECIFIC LATENT HEAT OF vaporization OF Water:

"Amount of heat required to change unit mass of a liquid to vapour state at the boiling point without change in temperature is called SPECIFIC LATENT HEAT OF VAPORIZATION.

$$(L_v)_{Water} = 2260\frac{J}{g} = 2260{,}000\frac{J}{kg}$$

* This topic is not present in our course book, thus it is not important for exams. However its understanding is necessary for the numerical of law of heat Exchange.

LAW OF HEAT EXCHANGE

DEFINITION:

"When a hot is in thermal contact with a cold body the amount of heat lost by the hot body is equal to the amount of heat gained by the cold body."

MATHEMATICAL EXPRESSION:

$$\begin{pmatrix}\text{Heat Lost}\\ \text{by Hot Body}\end{pmatrix} = \begin{pmatrix}\text{Heat Gained}\\ \text{by COld Body}\end{pmatrix}$$

THE SPECIFIC HEAT OF POLYATOMIC GASES IS GREATER THAN SPECIFIC HEAT OF MONATOMIC GASES

REASON:

The molecules of monatomic gases have only translational KE, while the molecules of polyatomic gases may have rotational KE, vibrational KE and PE in addition to translational KE. The heat supplies to a monatomic gas is used to increase its translational KE, but the heat supplied to polyatomic gases is used to increase translational KE, rotational KE, vibrational KE and PE of molecules. Temperature of a gas depends only upon translational KE of molecules. Thus for same rise of temperature more have has to supplied to a polyatomic gas than that supplied to a monatomic gas, consequently, the specific heats of monatomic gases are less than those of diatomic or triatomic gases.

IDEAL & REAL GASES – COMPARISON

IDEAL GASES	REAL GASES
1. DEFINITION	
A gas which obeys gas laws at all temperature and pressure is called an Ideal or perfect Gas	A gas which obeys gas laws at high temperatures and low pressure (where the volume is high and gas particles are far away) is called **REAL GAS.**
2. MOLECULES	
An ideal gas is based on the point-molecule model, i.e it consists of infinitely small, elastic particles(The assumption applies fine to monatomic gases)	The molecules of real gases are not point masses e.g we can see diatomic molecules as two point masses like an elastic dumbbell.
3. INTERMOLECULAR FORCES	
In ideal gases the molecules do not exert any force on each other.	In real gases there are weak forces of attraction between, the molecules (**VANDER WAALS' FORCES** or **LONDON FORCE**)
4. KINETIC ENERGIES	
In ideal gases molecules always move in straight lines, they have translational KE only.	In real gases, molecules may have Kinetic energies associated with their linear motion their rotation about an axis or their vibratory motion. Thus they may have translational K.E, rotational KE, vibrational KE, or all of these

1ST LAW OF THERMODYNAMICS

INTRODUCTION:

1st law of thermodynamics is an extension of law of conservation of energy to include heat.

STATEMENT:

"The amount of heat transferred to or from a thermodynamic system is equal to the change in internal energy of the system plus the work dons inside the system."

Or

"The internal energy of an isolated system always remains constant."

Mathematical form:

Then the 1st law of thermodynamics implies that.

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

SIGN CONVENTION:

i. **AMOUNT OF HEAT:**
If heat is supplied to the system, Q is taken **POSITIVE**
If heat is given by the system, Q is taken **NEGATIVE**

ii. **WORK DONE:**
If work is done by the system, *W*s taken **POSITIVE**
If work s done on the system, W is taken **NEGATIVE**

iii. **CHANGE IN INTERNAL ENERGY:**
If internal energy of the system increase, ΔU is taken **POSITIVE**
If internal energy of the system decrease, ΔU is taken **NEGATIVE**

SPECIAL CASES:

(1) ISOLATED SYSTEM:

DEFINITION:

"A thermodynamics system which can neither do work nor can affored heat transfer is called ISOLATED SYSTEM."

MATHEMATICAL FORM:

For an isolated system, $Q = 0$ & $w = 0$

According to 1st law, $Q = \Delta U + W$

$0 = \Delta U + 0$

$\boxed{\Delta U = 0}$

Thus, **"The internal energy of an isolated system remains constant."**

(2) CYCLIC PROCESS:

DEFINITION:

"When a system attains its initial stat after undergoing a series of changes, the process is called **CYLIC PROCESS**."

$\Delta U = 0$

According to 1st law, $Q = 0 + W$

$\boxed{Q = W}$

Thus, **"The heat supplied to a system in a cyclic process equals the work done during the process."**

INTERNAL ENERGY IS A STATE VARIABLE, WHILE HEAT AND WORK ARE NOT:

If the same system is taken from the same initial state 'i' to same final state 'f' through different processes. It is found that the value of ΔU remains same this indicate that ΔU is independent of the path followed by the system and depend only upon initial and final states o the system. This establishes internal energy internal energyas a characteristic property (state variable) of the system.

Both heat and work not only depend upon initial and final states, but also on the path process, this dependence on path suggest that heat and work are not the forms of energy contained in a system, rather they represent energy in the process of transfer. Thus, heat and work are not state variables.

SIGNIFICANCE OF THE 1ST LAW:

(1) It indicates the possibility of converting various forms of energy into heat, and vice versa.
(2) It reveals that internal energy of a system can be increased by adding heat or doing work on the system.
(3) It indicates that internal energy is a state variable and is characteristic of the system.
(4) It makes no distinction between heat and work, and indicates that both represent forms of energy in transfer. Thus they are not state functions.
(5) It puts no restriction on the types of energy conservations.

LIMITATIONS OF THE 1st LAW:

(1) If does not take into account the equality or usefulness of energy.
(2) It is not capable of indicating the direction of change of the system or direction of reaction.
(3) It cannot help in knowing whether a chemical change, alone will occur or not.
(4) It cannot define the extent of convertibility of one form of energy into another.

APPLICATIONS OF 1st LAW OF THERMODYNAMICS

(1) ISOBARIC PROCESS:

DEFINITION:

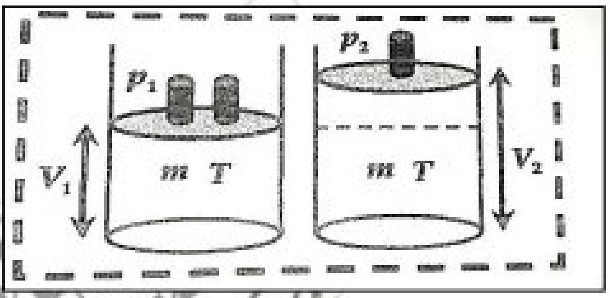
"A thermodynamic process in which the pressure of the system remains constant is called ISOBARIC PROCESS."

EXPLANATION:

We consider an ideal gas enclosed in a piston-cylinder system, consisting of a cylinder fitted witha weightless, frictionless, air-tight and movable piston of area A. The piston and the cylinder walls are non-conducting; only its base is conducting.

Initially the gas pressure is p, its volume is V_1, its temperature is T_1 and its internal energy is U_1 keeping pressure constant at p heat Q_p is supplied to the system. As a result the internal energy increase to U_2 and temperature to T_2

The gas molecules move more rapidly and push the piston up withup with a force F such that the piston is displaced through a height Δy and the gas volume increases to V_2.



MATHEMATICAL EXPRESSIONS:

The work done by the system (gas) is

$$W = Fs\cos\theta$$
$$W = F\Delta y\,(\cos 0) = F\,\Delta y\,(1)$$
$$W = F\Delta y \qquad \text{----①}$$

The gas pressure is

$$P = \frac{F}{A}$$
$$F = PA$$

Thus, eqn ① becomes

$$W = (PA)\,\Delta y$$
$$W = P(A\,\Delta y) \qquad \text{----②}$$

The volume of a cylinder of height h and cross-sectional area A is.

$$V = A.\,h = \pi r^2.\,h$$

From figure it is obvious that

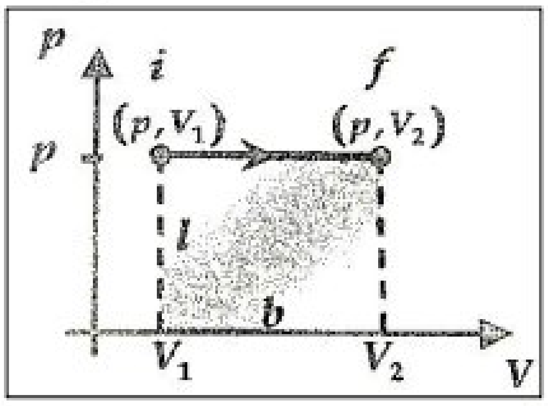
$$\Delta V = A\Delta y$$

The eqn ② becomes

$$\boxed{W = P\Delta V}$$

Applying 1st Law of thermodynamics,

$$Q = \Delta U + W$$
$$\boxed{Q_p = \Delta U + p\,\Delta V}$$



***PV* CURVE:**

The *PV* curve for an isobaric is a straight horizontal line showing constant pressure, called **ISOBAR**. The area under the *pV* curve is equal to the total work done during the process.

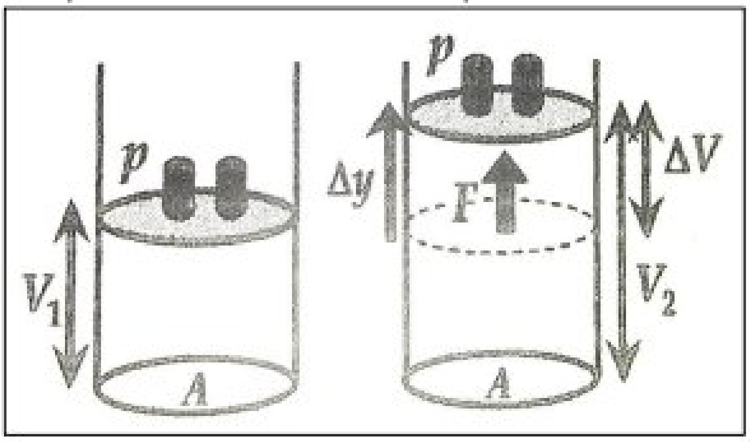
(2) ISOCHORIC PROCESS

Definition

"A thermodynamic process in which the volume of the system remains constant is called ISOCHORIC PROCESS."

EXPLANATION:

We consider an ideal enclosed in a piston-cylinder system, consisting of a cylinder fitted with a weightless, frictionless, air-tight and movable piston of area A. The piston and the cylinder walls are non-conducting; only its base is conducting. Additionally, stops are placed above and below the piston to make it immovable.



Initially the gas pressure is p_1, its volume is V_1, its temperature is T_1 and its internal energy is U_1 keeping volume constant at V heat Q_v is supplied to the system. As a result the internal energy increase to U_2 and temperature to T_2 the gas molecules move more rapidly and the internal pressure of the gas increases to p_2.

MATHEMATICAL EXPRESSIONS:

The work done in a thermodynamic process is given by

$$W = P\Delta V$$

In this case, $\boxed{\Delta V = 0}$

$$W = p(0) = 0$$

Applying 1st Law of thermodynamics,

$$Q = \Delta U + w$$

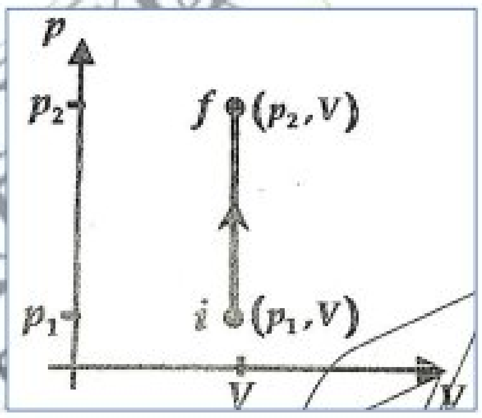
$$Q_V = \Delta U + 0$$

$$\boxed{Q_V = \Delta U}$$

***pV* CURVE:**

The pV curve for an isobaric is a straight Vertical line showing constant volume, called **ISOCHOR**.

The area under this pV curve is Zero, showing no work is done during the process.



$$\begin{pmatrix} Area\ under \\ pV\ curve \end{pmatrix} = W = p\Delta V = 0$$

(3) ISOTHERMAL PROCESS:

DEFINITION:

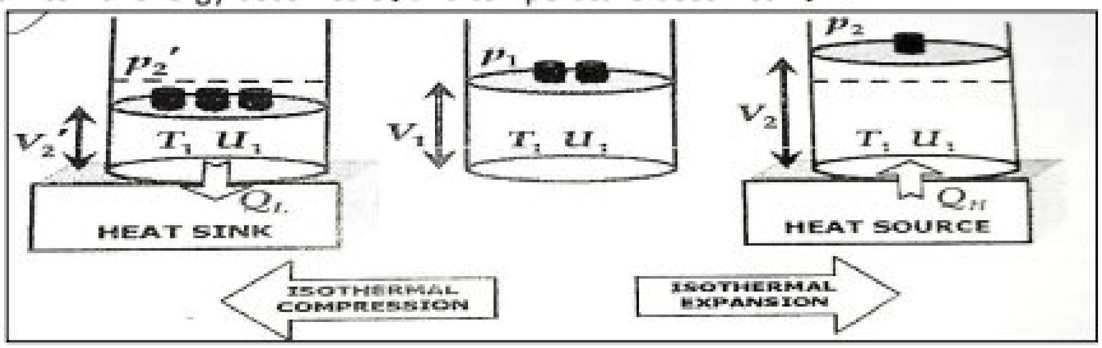
"A thermodynamic process in which temperature of the system remains constant is called ISOTHERMAL PROCESS."

EXPLANATION:

We consider an ideal enclosed in a piston-cylinder system, consisting of a cylinder fitted with a weightless, frictionless, air-tight and movable piston of area A. The piston and the cylinder walls are non-conducting; only its base is conducting. Initially the gas pressure is p_1, its volume is V_1, its temperature is T_1 and its internal energy is U_1.

ISOTHERMALEXPANSION:

The pressure is decreases to p_2, due to which the volume increases to V_2. During expansion the internal energy and temperature decrease. The system is placed on a **HEAT SOURCE***at temperature T_1. To compensate the loss of internal energy, the source supplies heat Q_H to the system until thermal equilibrium is reached. The internal energy becomes U_1 and temperature becomes T_1.



ISOTHERMAL COMPRESSION:

The pressure is increased to p_2', due to which the volume decreases to V_2'. During compression, the internal energy and temperature increase. The system is placed on a **HEAT SINK**[+] at

*A heat source is a body which can supply infinite amount of heat without any decrease in its own temperature. Close approximations are the Sun, the Nuclear Fission Chain Reaction, etc.

[+] A heat sink is a body which can absorb infinite amount of heat without any increase in its temperature.Close approximations are the Oceans, the atmosphere, etc.

Temperature T_1 to counter the gain of internal energy, the sink absorbs heat Q_1 from the system until thermal equilibrium is reached. The internal energy becomes $U_1$and temperature becomes T_1.

MATHEMATICAL EXPRESSIONS:

In an isothermal process the temperature of the system remains constant, i.e.

$$\boxed{\Delta U = 0}$$

Applying 1st Law of thermodynamics,

$$Q = \Delta U^0 + W$$

$$\boxed{Q = W}$$

For ISOTHERMAL EXPANSION,

$$\boxed{+Q_H = +W}$$

For ISOTHERMAL COMPRESSION,

$$\boxed{-Q_L = -W}$$

General Mathematical form is

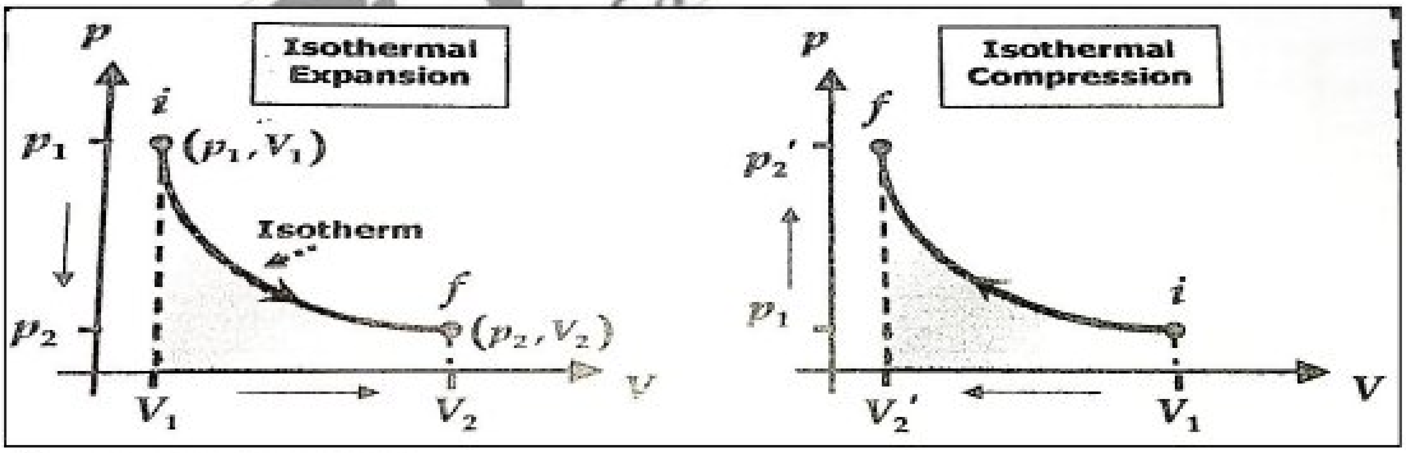
$$\boxed{\pm Q = \pm W}$$

ISOTHERMAL FORM OF BOYLE'S LAW:

$$\boxed{PV = \text{constant}} \qquad \text{(At const } T\text{)}$$

***PV* CURVE:**

The pV curve for an isothermal process is a hyperbolic curve called **ISOTHERM**. The area under the isotherm represents the work done during the isothermal process.



(4) ADIABATIC PROCESS:

DEFINITION:

"A thermodynamic process in which there is no heat transfer to or from the system is called ADIABATIC PROCESS."

EXPLANATION:

We consider an ideal gas enclosed in a piston-cylinder system, consisting of a cylinder fitted witha weightless, frictionless, air-tight and movable piston of area A. The piston and the cylinder walls are non-conducting; only its base is conducting. Initially the gas pressure is p_1, its volume is

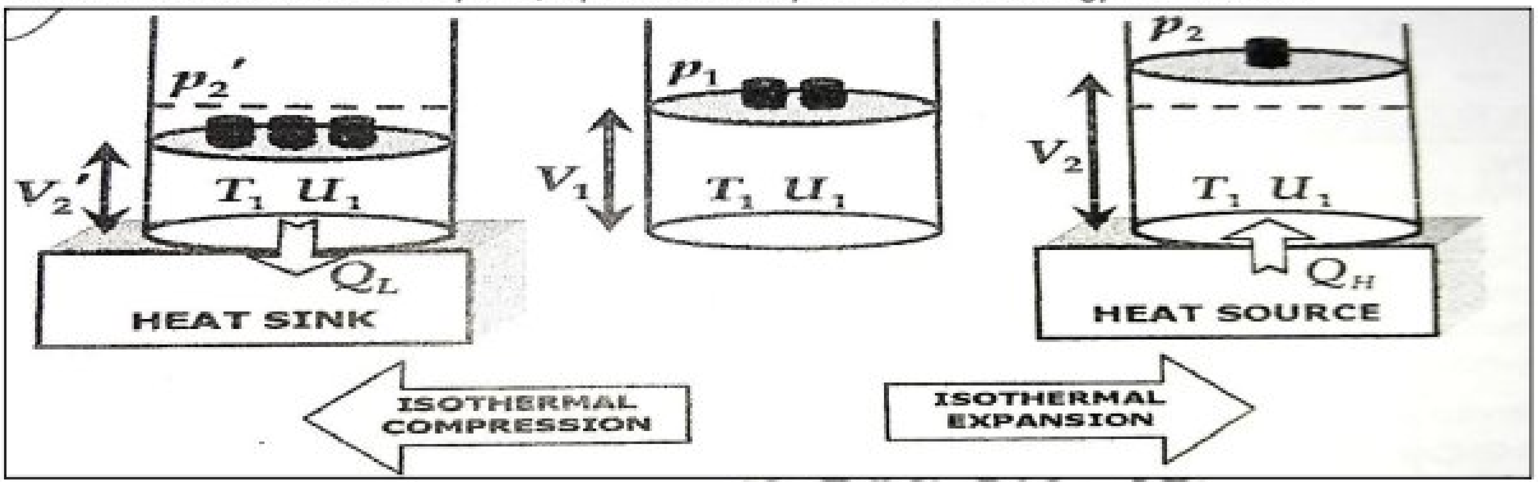
V_1, its temperature is T_1 and its internal energy is U_1.

ADIABATICEXPANSION:

The pressure is decreases to p_2, by slowly pulling the piston upwards, due to which the volume increases to V_2 .During expansion the internal energy and temperature decrease$U_2 or T_2$. The system is placed on a **HEAT Insulator,**thus it cannot gain internalenergy.As the system has expanded i.e.work has been done by the system, it plausible that system's internal energy has decreased.

ADIABATIC COMPRESSION:

The pressure is increases to p_2, by slowly pushing the piston downwards, due to which the volume decreases to V_2 .During compression the internal energy and temperature increase$U'_2 and T'_2$. The system is placed on a **HEAT INSULATOR,**thus it cannot gain internalenergy. As the system has been compressed i.e. work has been done on the system, it plausible that system's internal energy has increases.



MATHEMATICAL EXPRESSIONS:

In an adiabatic process there is no heat transferof or from the system, i.e.

$\boxed{Q = 0}$

Applying 1st Law of Thermodynamics,

$Q^0 = \Delta U + W$

$0 = \Delta U + W$

For ADIABATIC EXPANSION,

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

For ADIABATIC COMPRESSION,

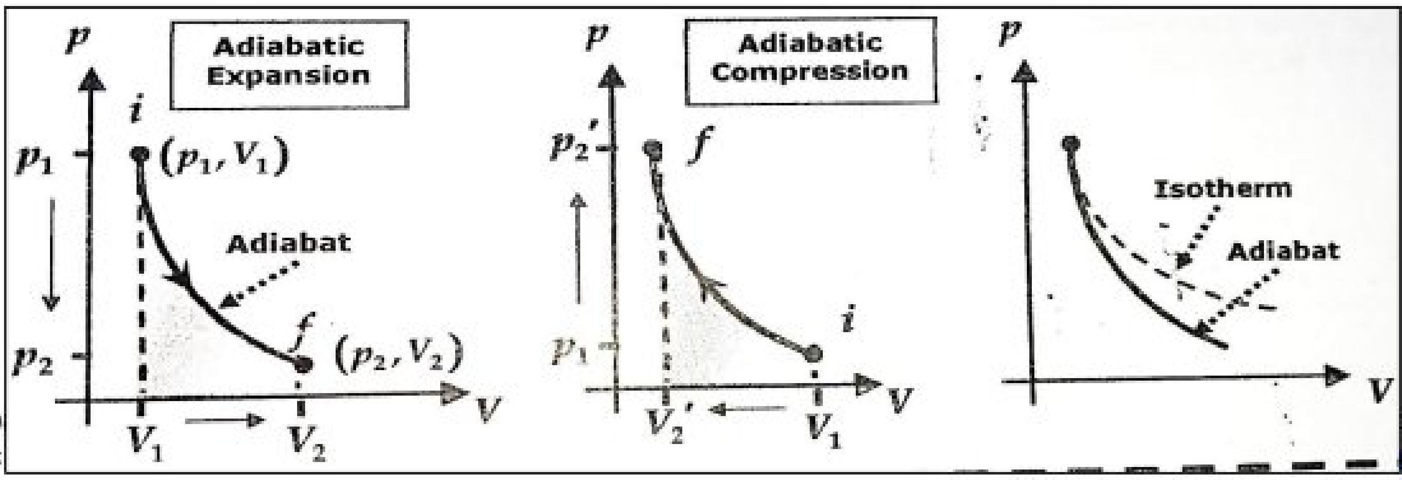
$\boxed{-W = +\Delta U}$

General Mathematical form is

$\boxed{\pm W = \pm \Delta U}$

ADIABATIC FORM OF BOYLE'S LAW:

$\boxed{PV^{\gamma} = \text{constant}}$ where $\gamma = \frac{C_p}{C_V}$

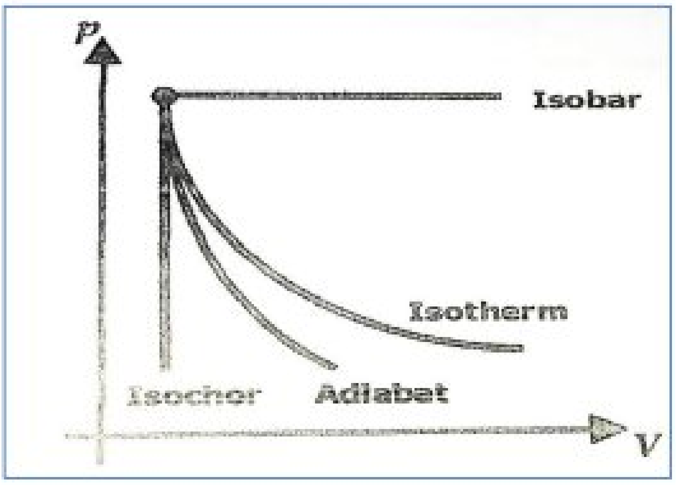


PV CURVE:

The pV curve for an adiabatic process is a **hyperbolic curve** called **ADIABAT,** which is steeper than an isotherm.

The area under the adiabatic represents the work done during the adiabatic process, which is less than the work during an isothermal process.

GRAPHICAL COMPARISON OF THERMODYNAMIC PROCESSES:



DEFFERENCE OF MOLAR SPECIFIC HEATS OF IDEAL GAS

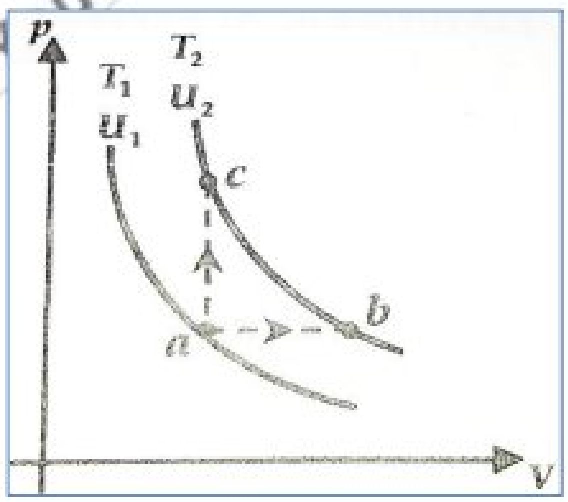
(Prove that $C_p - C_v = R$)

MATHEMATICAL DERIVATION:

We consider two ideal gas isotherms, one at temperature T_1 and other at temperature T_2. The internal energy of a gas depends only upon its temperature, thus the internal energy for the two isotherm at U_2. Take n as the number of moles of the gas. The change in temperature will be

$$\Delta T = T_2 - T_1$$

We change the temperature of the gas in two different ways: at constant pressure and at constant volume.



CHANGE IN TEMPERATURE AT CONSTANT PRESSURE:

The heat to change temperature in constant-pressure process is

$$Q_p = nC_p\Delta T$$

$$Q_p = \Delta U_{ab} + W$$

$$\Rightarrow \quad nC_p\Delta T = \Delta U_{ab} + P\Delta V$$

From General Gas Equation,

$$PV = nRT$$

For initial state (1st isotherm) $\quad PV_1 = nRT_1$

For final state (2nd isotherm) $\quad PV_2 = nRT_2$

We can write

$$PV_2 - PV_1 = nRT_2 - nRT_1$$

$$\Rightarrow \quad P(V_2 - V_1) = nR(T_2 - T_1)$$

$$\Rightarrow \quad P\Delta V = nR\Delta T$$

Thus, we have

$$nC_p\Delta T = \Delta U_{ab} + nR\Delta T \quad \ldots\ldots (1)$$

CHANGE IN TEMPERATURE AT CONSTANT VOLUME:

The heat to change temperature in constant-volume process is

$$Q_v = nC_v\Delta T$$

$$\Rightarrow \quad Q_v = \Delta U_{ac} + W$$

$$\Rightarrow \quad nC_v\Delta T = \Delta U_{ac} \quad \ldots\ldots (2)$$

It is obvious that the change in internal energy over all paths connecting the 1st isotherm to the 2nd isotherm will be equal, which is mathematically $\Delta U = U_2 - U_1$. In other words, the change in internal energy depends only upon initial and final states and is independent of path. Thus,

$$\Delta U_{ab} = \Delta U_{ac} = \Delta U \quad \ldots\ldots (3)$$

Thus, we rewrite eq (2) as follows

$$nC_v\Delta T = \Delta U$$

putting this value of ΔU in eq (1)

$$nC_p\Delta T = \Delta U + nR\Delta T$$

$\Rightarrow$ $nC_p\Delta T = nC_v\Delta T + nR\Delta T$

$\Rightarrow$ $n\Delta TC_p = n\Delta T(C_v + R)$

$\Rightarrow$ $C_p = C_v + R$

$\Rightarrow$ $C_p - C_v = R$

Thus, "the difference of specific heats of gases is equal to the universal gas constant."

RATIO OF MOLAR SPECIFIC HEAT OF IDEALS GAS:

$$\left(Prove\ that\ \gamma = \frac{C_p}{C_V} = \frac{5}{3} = 1.66\right)$$

MATHEMATICAL DERIVATION:

Consider 1 mole of a monatomic (ideal) gas. We know from Kinetic-Molecular Theory that

$$\text{A.T.K.E. of a gas molecule} = \frac{3}{2}kT$$

1 mole of a gas contains Avogadro's number of molecules N_A, thus we will write

$$\textbf{T.K.E. of the gas } N_A = \left(\frac{3}{2}kT\right) = \frac{3}{2}N_A kT$$

$$\textbf{T.K.E. of the gas} = \frac{3}{2}RT \qquad \left[\begin{array}{l} k = \frac{R}{N_A} \\ \Rightarrow R = N_A K \end{array}\right]$$

The molecules of monatomic (ideal) gases do not have rotational KE, vibrational KE or PE; they only have translational KE. Thus, the internal energy of the gas is equal to the translational kinetic energy of the gas, i.e.

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

If this gas is heated at constant volume from temperature T_1 to temperature T_2, then

$$U_1 = \frac{3}{2}RT_1$$

And $$U_2 = \frac{3}{2}RT_2$$

The change in internal energy will be

$$\Delta U = U_2 - U_1$$

$$\Delta U = \frac{3}{2}RT_2 - \frac{3}{2}RT_1 = \frac{3}{2}R(T_2 - T_1)$$

For a constant volume (isochoric) process,

$$Q_V = \Delta U + W^0$$

$$Q_V = \Delta U$$

$$Q_V = \frac{3}{2}R\Delta T \qquad \text{(from eqn (1))}$$

$$\frac{Q_V}{\Delta T} = \frac{3}{2}R \qquad \text{-------(2)}$$

By definition of molar specific heat at constant volume,

$$C_V = \frac{Q_V}{n\,\Delta T} = \frac{Q_V}{(1)\,\Delta T}$$ In this case $n = 1$

$$C_V = \frac{Q_V}{\Delta T}$$

$$\boxed{C_V = \frac{3}{2}R}$$

Thus, eqn ② becomes:

Since $C_p - C_V = R$

$$C_p - C_V = R$$

$$C_p = \frac{3R}{2} + R - \frac{3R+2R}{2}$$

$$\boxed{C_p = \frac{5}{2}R}$$

The ratio of molar specific Heat at constant Pressure' to molar specific heat at constant volume is expressed as

$$\boxed{\gamma = \frac{C_p}{C_V}}$$

$$\gamma = \frac{\frac{5}{2}R}{\frac{3}{2}R}$$

$$\boxed{\gamma = 5/3 = 1.66}$$

The molecules of polyatomic gases possess translational KE, rotational KE, vibrational KE and PE. Thus, the value of γ for these gases is different. For example, the value of γ for air is **1.51**.

17 2ND LAW OF THERMODYNAMICS

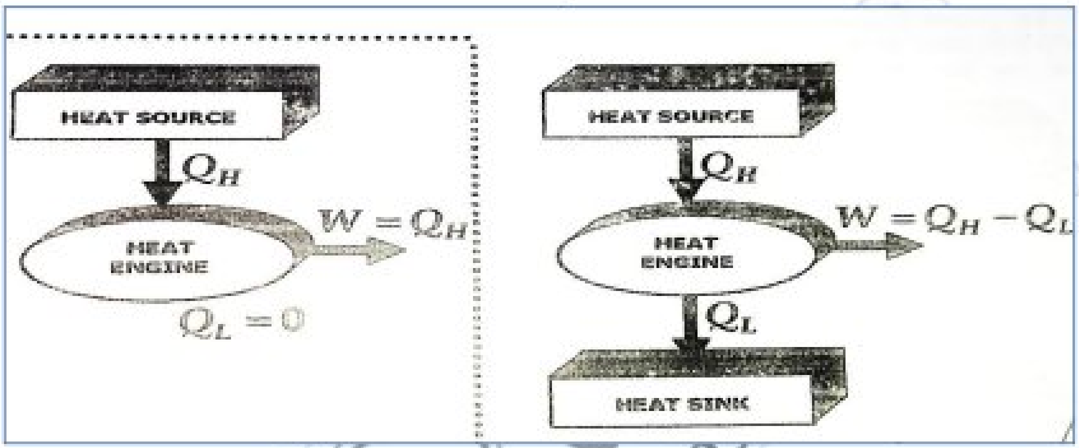
2ND LAW OF THERMODYNAMICS

INTRODUCTION:

The 2nd Law of Thermodynamics is a general expression of the fact that there is a preferred direction for a natural process to occur, and that every system. Naturally evolves with time in one direction but not the other. It is an expression of one-sidedness of the nature.

There are many equivalent statements of the law, the best acknowledge of which are those of lord kelvin and Rudolf clausius.

LORD KELVIN'S STATEMENT (OR HEAT-ENGINE STATEMENT):



STATEMENT:

"It is impossible to construct a heat engine which takes heat from a source and converts it completely into work by a cyclic process, without rejecting a part of this heat to a sink."

Or

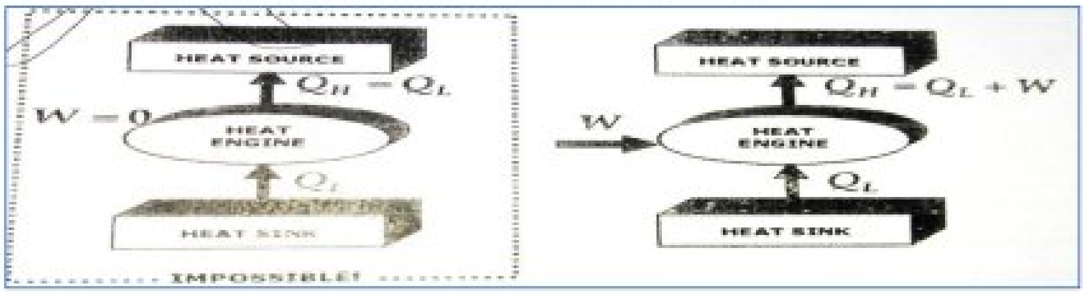
"Conversion of heat into mechanical work is impossible in the absence of a sink.

EXPLANATION:

"The device which converts heat energy into mechanical work is called HEAT ENEINE; however some heat has to be reject to sink.

A heat engine absorbs heat from a heat source, converts a part of it into work, and rejects the rest of this heat to a heat sink. This means that two bodies with a temperature difference are essential for the working of a heat engine. Due to rejection of same input heat to the sink, a heat engine cannot convert all heat into work.

RUDOLF CLAUSIUS' STATEMENT (OR Refrigerator statement):



STATEMENT:

"It is impossible to cause heat to flow from a cold body to a hot body without expenditure of energy (as in a refrigerator)."

Or

"it is impossible for any process to have its sole result the transfer of heat from a colder to a hotter body.

Or

"Energy must be supplied to the system for a non-spontaneous process to occur."

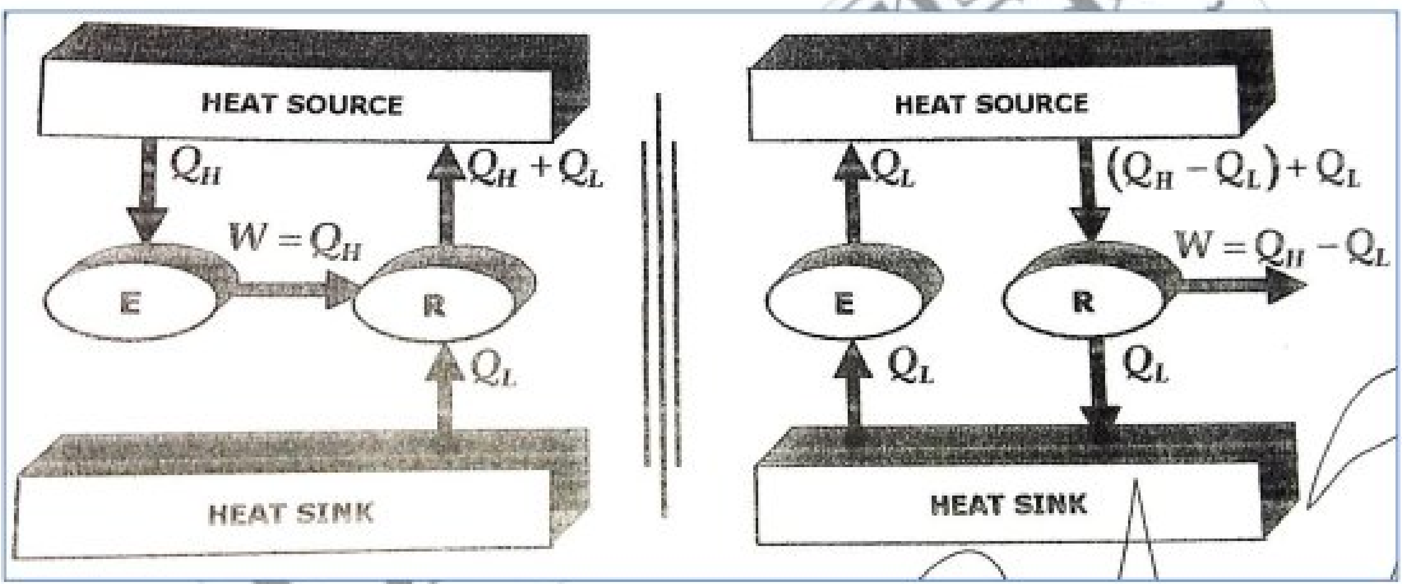
EXPLANATION:

"A refrigerator is a device which extracts heat from a heat from a heat sink and transfers it to a heat source; however external energy is required for this operation."

A household refrigerator takes heat from its interior (cold body) and rejects more heat to the room atmosphere (hot body). But for this process, electrical work is done on the refrigerator.
An air-conditioner is a special refrigerator which takes heat from within a room and exhausts it to the outdoor atmosphere, thus cooling the room.

EQUIVALENCE OF KELVIN'S & CLAUSIUS' STATEMENT:

To prove the equivalence of the two statement, we show that violating any one statement causes a violation of the other statement.



VIOLATION OF KELVIN'S STATEMENT COLLATES CLAUSIUS STATEMENT:

We consider an engine working between two reservoirs. It reject no heat to the sink and thus violates the kelvin's statement. Suppose a refrigerator is also working between the same two reservoirs, and uses up all the energy liberated by the engine, The refrigerator violates no law, but the engine and the refrigerator together constitute a self-acting device whose sole effect is to transfer heat Q_LFrom the sink to the source. Thus, the composite device violates the calusius statement.

VIOLATION OF CLAUSIUS STATEMENT COLLATES KELVIN'S STATEMENT:

We consider a refrigerator working between two reservoirs. It requires no input work to transfer heat **Q_L**from the sink to the source and thus, violates the clausius statement. Suppose an engine also operates between the same two reservoirs, which takes heat Q_H from the source converts a part of it into work and reject heat QL to the sink. The engine violates no law, but the engine and refrigerator together constitute a self-anting device whose sole effect is to take heat
$Q_H - Q_L$ from hot reservoir and convert all this heat into work. Thus, the composite device violates Kelvin's statement.

MAX PLANK'S STATEMENT (OR ENTROPY STATEMENT):

STATEMENT:

"Every process in nature, takes place such that the entropy of an isolated system either remains constant or increases.($\Delta S \geq 0$)"

CARNOT ENGINE

INTRODUCTION:

In **1824**, a French engineer **SADI CARNOT** deviseda hypothetical ideal engine with maximum possible efficiency, to prove that the efficiency of even an ideal engine cannot be 100%.

CARNOT THEOREM:

"The efficiency of a heat engine working between two temperature cannot be greater than the efficiency of a reversible heat engine (like Carnot Engine) working between the same temperature range."

ASSUMPTIONS:

(1) The Carnot Engine works on a **REVERSIBLE** thermodynamic process, called **Carnot cycle.**
(2) There are no heat losses due to **RADIATION** or **CONDUCTION**.
(3) There are no heat losses due to **FRICTION**.
(4) An **IDEAL GAS** will be used as the working substance.

CONSTRUCTION:

The Carnot Engine consists of an ideal gas enclosed in a piston-cylinder system consisting of a cylinder fitted with a weightless, frictionless, air-light and movable piston. The piston and the cylinder walls are non-conducting; only its base is conducting.
There are two bodies of high thermal capacities, one at higher temperature **(SOURCE)** and the other at low temperature **(SINK)**.A perfect insulating body is also to ensure adiabatic processes.

WORKING (THE CARNOT CYCLE):

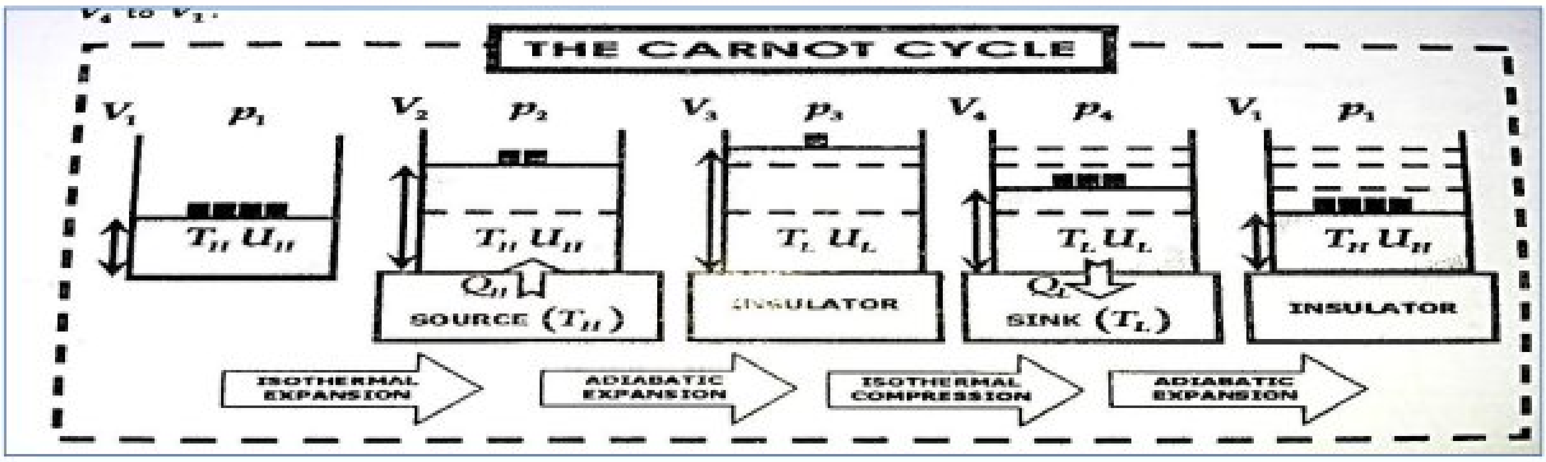
The Carnot Engine is worked through four discrete thermodynamic processes in a sequence, which constitutes a reversible thermodynamic cycle commonly called **CARNOT CYCLE**.

STEP I (ISOTHERMAL EXPANSION):
The cylinder is placed on the heat source at temperature T_H. The gas is allowed to expand at constant temperature T_H and constant internal energy U_H, by continuously absorbing heat Q_H from the source. The gas volume increases from V_1 to V_2.

STEP II (ADIABATIC EXPANSION):
The cylinder is placed on the insular and the gas is allowed to expand adiabatically. As no heat is absorbed, the temperature drops to T_L and the internal energy to U_L the gas volume increases from V_2 to V_3.

STEP III (ISOTHERMAL COMPRESSION):
Now the cylinder is placed on the heat sink at temperature T_L. The gas is compressed at constant temperature T_L and constant internal energy U_l. By continuously rejecting heat Q_L to the sink. The gas volume decreases from V_3 **to** V_4.

STEP IV (ADIABATIC COMPRESSION):
The cylinder is again placed on the insulator and gas is compressed adiabatically. As no heat is rejected, the temperature rises to T_H and the internal energy to U_H. the gas volume decreases from V_4 **to** V_1.



EFFICIENCY OF CARNOT ENGINE:

The percent efficiency of a heat engine is given as

$$\eta = \frac{Output}{Input} \text{ x } 100$$

$$\eta = \left(\frac{W}{Q_H}\right) \text{ x } 100$$

$$\eta = \left(\frac{Q_H - Q_L}{Q_H}\right) \text{ x } 100 = \left(\frac{Q_H}{Q_H} - \frac{Q_L}{Q_H}\right) \text{ x } 100$$

$$\%\eta = \left(1 - \frac{Q_L}{Q_H}\right) \text{ x } 100$$

We can can write for the source and the sink

$$Q_H \alpha\ T_H \qquad\qquad Q_L \alpha\ T_L$$

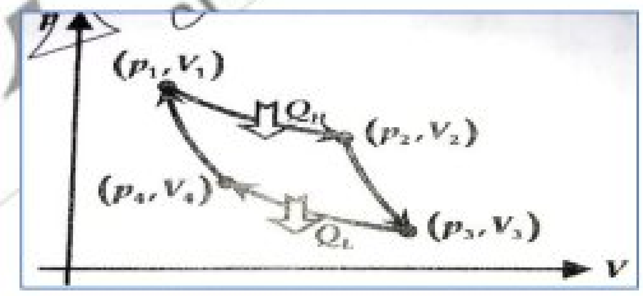
$$\Rightarrow Q_H \alpha\ kT_H \qquad\qquad \Rightarrow Q_L = kT_L$$

Dividing the two expressions, $\frac{Q_H}{Q_L} = \frac{T_H}{T_L}$

The percent efficiency can be expressed as

$$\eta = \left(1 - \frac{T_L}{T_H}\right) \text{ x } 100$$

GRAPHICS REPRESENTATION:



CONCLUSIONS:

(1) The efficiency of Carnot engine can be 100% if the factor $\frac{T_L}{T_H}$ or $\frac{Q_L}{Q_H}$ becomes zero.

(2) The efficiency of Carnot engine can be 100% if the sink is at absolute zero (-273 °C) temperature i.e. the engine rejects no heat to the sink. This is impossible as per 3rd Law of Thermodynamics; **"A body cannot attain absolute zero in a finite number of steps"**.

(3) Alternatively, the efficiency of Carnot engine can be 100% if temperature of source is infinity i.e the engine absorbs infinite amount of heat. This is also impossible.

(4) As a result of the above two facts, the efficiency of even a Carnot engine (with no irreversibility and no heat losses) cannot be 100%.

ENTROPY

DEFINITION:

"The measure of low-quality energy (energy that cannot yield work) in a thermodynamic system is called Entropy. In other words, it is the measure of unavailability of high-quality energy (energy that can readily be converted to work). Since work is obtained from order, the amount of entropy is also a measure of the disorder or randomness of a system."

MATHEMATICAL EXPRESSION:

The change in entropy of a system during a thermodynamic process is given as.

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

SIGN CONVENTION:

(1) When heat is added to a system the entropy change is **POSITIVE**.

(2) When heat is removed from a system, the entropy change is NEGATIVE.

SI Unit: $\frac{J}{K} = J.K^{-1}$ (Joule per Kelvin)

EXAMPLES:

The following natural process illustrate the increase in entropy

- Spontaneous mixingof hot and cold gases.
- The uncontrolled expansion of a gas into vacuum
- The combustion of fuel.

ENTROPY & UNAVAILABILITY OF HIGH-QUALITY ENERGY:

In all natural process energy tends to pass from available (high-quality) from to a less available (Degraded) from. This DEGRADATION OF ENERGY increases, the entropy of the system.

Thus, entropy measures unavailability of high-quality energy in a system.

ENTROPY & MOLECUALR DISORDER:

The amount of work produced during a process decreases if the molecular disorder of the system increases. Thus the change of entropy corresponds to the molecular disorder or randomness of a system.

EXPLANATION:

Consider large number of gas molecules in an insulated container with removable partition, dividing the system into two equal halves Let $V_i = V$. when the partition is removed the molecules will occupy volume $V_f = 2V$.Now the molecules are less localized i.e. the disorder has increased as has entropy.

CONSERVATION OF ENTROPY IN REVERSIBLE PROCESSES:

In reversible processes, the entropy of the system remains conserved i.e $\Delta S = 0$

2ND LAW IN TERMS OF ENTROPY (OR LAW OF INCREASE OF ENTROPY)

STATEMENT:

2nd law of thermodynamics can be restated in terms of entropy as:

"Every process in nature, takes place such that the entropy of an isolated system either remains constant or it increases"

Thus, 2nd Law is also called **LAW OF INCREASE OF ENTROPY**.

NON-CONSERVATION OF ENTROPY IN NATURAL (IRREVERSIBLE) PROCESSES:

All irreversible processes involve an increase in entropy. Since all natural processes are reversible the 2nd Law reveals that all natural processes proceed towards a state of greater entropy i.e. unavailability of high-quality energy and greater disorder.

The total amount of energy in all natural processes remains constant (according to 1st Law), but total entropy must increase (according to 2nd law) Thus, the entropy of a system does not remain conserved.

HEAT DEATH OF UNIVERSE:

Clausius predicted that, **"The entropy of the universe tends towards a maximum."**
This means that at a certain stage the entropy of the universe will become infinity high, and useful energy of all forms will become highly unavailable. Consequently, all the processes in the universe will cease to function.
This is known as **HEAT DEATH OF UNIVERSE**.

ENTROPY AS A TIME-ARROW:

All natural events always occur in the direction of increasing entropy with lapse of time. Thus, entropy is truly referred as **TIME-ARROW**.

REASONING QUESTIONS

Q.1. Why is average velocity of the molecules in a gas is zero but the average of the square of the velocities is not zero?

There is a large number of molecules in a gas. According to our assumption, equal number of molecules move in all directions, It means that the number of molecules moving to the right in x - direction is equal to the number of molecules moving to the left in the opposite direction with the same velocity. Thus, the vector sum of their velocities will be zero. But the square of the negative velocity i.e. $[(-v)^2 = v^2]$ is also a positive, therefore the average of the square of the velocities will not be zero.

Q.2.Why does the pressure of a gas in a car tyre increase when it is driven through some distance.

When a car is driven through some distance, work done by the car is partly spent in overcoming the frictional force between the road and the car tyre. Some part of work done against frictional is converted into heat-which raises the temperature of the gas in a car tyre. As we know that pressure is directly proportional to absolute temperature at constant volume, therefore the pressure must increase because the heat energy increases the velocity and collisions of gas_ molecules, As a result, molecular collisions against the walls of a tyre increase the pressure of air inside the tyre.

Q.3. Specific heat of a gas at constant pressure is greater that specific *heat at constant volume. Why?*

When a gas is heated at constant pressure, then the heat supplied is used in two ways.

(i) *Some part of heat is used in doing the external work to move the piston up against the constant atmospheric pressure.*

(ii) *The other part of heat is used to increase the internal energy and temperature.*

If the same gas is heated at constant volume, no external work is done to expend the gas. The total heat supplied is used to increase the internal energy and temperature of the gas. This shows that more heat is required to heat the gas at constant pressure than at constant volume for the same rise of temperature. So we conclude that specific heat at constant pressure if greater than the specific heat at constant volume i.e. $C_p > C_v$.

Q.4. Give an example of process in which no heat is transferred to or from the system but the temperature of the system changes.

Adiabatic process is an example of such a process.
Consider a gas enclosed in a non-conducting cylinder by a non-conducting piston. If the gas is compressed, the work done on the gas will increase its temperature but no heat will leave the system. Conversely, if the gas is allowed to expand, the work done by the gas at the cost of its internal energy will decreases its temperature but no heat will enter the system. This compression or expansion of the gas is adiabatic in nature because no heat is transferred to or from the system but its temperature changes.

Q.5. Is it possible to convert internal energy into mechanical energy?

Yes, it is possible to convert internal energy into mechanical energy. Applying the first law of thermodynamics to an adiabatic process.

$$Q = U + W$$

In such process, Q = 0 then

$$U = - W$$

If work done 'AW' is negative then. The work is done at the cost of internal energy. This means if a system (gas) is allowed to expand adiabatically some work is done at the cost of internal energy. Thus internal energy decreases because some quantity of internal energy has been converted into mechanical work.

EXAMPLES:-

1. Gases can be liquefied by this process.
2. In case of heat engines (e.g. petrol engine) the hot gases expand and the piston moves backward. In this way also internal energy is converted into work (i.e. mechanical energy)

Q. 6. Is it possible to construct a heat engine that will not expel heat into the atmosphere?

No, it is not possible to construct a heat engine that will not expel heat into the atmosphere. According to Newton's second law of thermodynamics, all the practical heat engines absorb heat from the source, convert a part of it into mechanical work and reject the remainder to the cold body or atmosphere. Hence, no heat engine can operate with a single source for conversion of heat into, mechanical work without expelling heat to the atmosphere. In other words, there must be a - temperature difference between the hot and cold bodies (source and sink) for the conversion of heat into mechanical work.

Q.7. A thermo flask containing milk as a system is shaken rapidly. Does the temperature of milk rise?

When the milk is shaken rapidly, the kinetic energy of the molecules of the milk increases which causes an increase in the temperature and internal energy. No heat is added to the milk. While we are shaking the milk, we do some work on it, which is converted into K.E. of molecules of milk.

Q. 8. What happens to the temperature of the room, when an air conditioner is left running on a table in the middle of the room?

An running air conditioner, placed on a table in the middle of room, rejects the heat through the compressor in the same room. Thus, no change in the room temperature will take place because the heat absorbed from the room is expelled or lost in the same room. Hence, there will be no effect on the temperature of the room,

Q. 9. Can mechanical energy be converted completely into heat energy?

Yes, the mechanical energy or work can be completely converted into
heat energy. When work (mechanical energy) is done in compressing the gas by adiabatic process, the increase in the internal energy *AU' of the gas is equal to the work done W on it. According to 1stlaw of thermodynamics, -

$$Q = \Delta U + W$$

But $Q = 0,$

and W = negative (work done on gas)

$$0 = \Delta U - W$$

or $\Delta U = W$

Reason: -The whole of the mechanical energy can be absorbed by the molecules of the gas in the form of their K.E. this K.E gets converted into heat.

EXAMPLES:-

When brakes of speeding car are applied, it stops which means that all of its K.E. is converted into heat. Second law of thermodynamics does not apply when work is being converted into heat. If we rub our hands, by rubbing them the whole mechanical energy is converted into heat energy.

Q. 10. Does entropy of a system increase or decrease due to friction?

If the work is done by friction, the work will be converted into heat. The heat produced due to the friction goes into the surrounding i.e. air and becomes useless. No useful work can be performed by it due to the, unavailability of this energy, we can say that the entropy will increase when work is done by friction. Hence the entropy of a system increases due to friction.

The TrueUniversity These Days Is A Collection Of Books.

18 MAGNETIC FIELDS

MAGNET:

"A body (a piece of a certain iron core, or a current- carrying loop) that possesses the property of attracting iron, nickel and cobalt, and can influence the motion off charges is called MAGNET."

CHARACTERISTICS:

(1) Magnets attract iron, nickel and cobalt.
(2) The magnetic force is strongest at the poles of the magnet and weakest at its center.
(3) If a magnet is suspended or pivoted to swing, freely, it always points in a definite direction such that one of its ends points towards the north and the other towards the south.
(4) **Like** poles **repel** each other and **unlike** poles **attract** each other.

MAGNETISM:

"The study of the nature and cause of magnetic fields and new different substances are affected by them is called MAGNETISM."

MAGNETIC FIELD

"The space around a magnet or a current carrying conductor another magnet or a moving charge can experience a force is called MAGNETIC FIELD."

The magnetic (strength) and direction of the magnetic field are indicated by vector$\vec{B}$.

MAGNETIC FIELD DUE TO ISOLATED CHARGES & CURRENT:

When an isolated charge is at rest, it only produces electric field around it. However, a moving charge produces both electric field and magnetic field around it.

Thus, there exists a magnetic field around a current-carrying conductor (straight or solenoid) due to flow of free electrons inside it. However, there exists no electric field around a current-carrying conductor as the electric field of moving electrons in a conductor is balanced by the electric field of conductor's protons.

ELECTRODYNAMICS:

DEFINITION:

"The branch of physics which studies the mechanical forces generated between neighbouring circuits when carrying electric currents is called ELECTRODYNAMICS."

ELECTROMAGNETISM:

DEFINITION:

"The branch of physics which deals with the interaction of electric and magnetic fields is called ELECTROMAGNETISM.

INTRODUCTION:

Michael faraday proposed the concept of magnetic lines to visualize magnetic field in a region.

DEFINITION:

"A magnetic line of induction is a continuous endless line drawn in a magnetic field such that the tangent to it at any point gives the direction of magnetic field at that point."

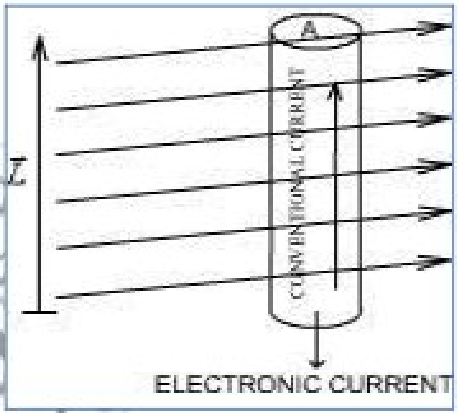
CHARACTERISTICS:

(1) Magnetic lines of induction are imaginary lines.
(2) These lines are drawn with respect to a (north) test pole, i.e. magnetic compassneedle.
(3) The tangent to magnetic line of inductionAt a point gives the direction of field at That point.
(4) They are endless and continuous lines.
(5) They never intersect each other.
(6) Dense (crowed) lines represent strongField.
(7) Parallel lines represent uniform field.
(8) The lines are drawn so that the number of lines per unit area placed perpendicular to the lines is proportional to the magnitude of magnetic field.

MAGNITIC FIELD DUE TO STRAIGHT CURRENT – CARRYING CONDUCTOR

OERSTED'S DISCOVERY:

In **1819, Hans Christian OERSTED** discovered that the current flowing in a conductor deflects the needle of a nearby magnetic Compass. He concluded that the deflection is due to magnetic field produced due to the Current passing through the wire.
He also noted that reversing the direction of current in the wire reversed the deflection in the needle.



MAXWELL'S RIGHT - HAND GRIP RULE:

The direction of magnetic lines due to a straight current-carrying conductor is determined to **MAXWELL'S RIGHT – HAND GRIP RULE.**

"Ifthe current-carrying wire is grasped in the right hand with The thumb pointing in the direction of current then the curled Fingers around the wire indicate the direction of magnetic lines.

DESCRIPTION OF MAGNETIC FIELD:

(1) The magnetic lines of induction are in the form of concentric circles in a plane perpendicular to the wire, with the wire as their center.
(2) If the current in the wire is in the upward direction, the magnetic lineswill be anticlockwise.
(3) If the current in the wire is download, the magnetic lines are in clockwisedirection.

AMPER'S CONTRIBUTION:

In **1820, Andre Marie Ampere** observed that,

(1) It two wires carrying current in same direction are placed parallel to each other they attract each other just like opposite poles of magnet.
(2) If two wires carrying current in opposite direction are placed parallel, there will be a force of repulsion between them.

MAGNETIC FLUX

INTRODUCTION NATURE & NOTATION:

The word flux comes from a latin word ***fluxus*** meaning "flow". It is a scalar quantity and magnetic flux is commonly denoted by Φ_B.

DEFINITION:

QUALITATIVELY:

"The total number of magnetic lines of induction crossing a surface placed normal to magnetic field is called **MAGNETIC FLUX**.

QUALITATIVELY:

"The dot product of magnetic induction and vector area is called MAGNETIC FLUX.

VECTOR AREA:

"Vector area is a vector quantity, the magnitude of which is the area of a surface and its direction is along the normal to the surface."

MATHEMATICAL EXPRESSION:

Consider a surface area A placed a magnetic field of induction $\vec{B}$, such that B is uniform over all points. The component of area $\vec{A}$ normal to $\vec{B}$ is $A_\perp$ = A cosθ.Thus,

$$\begin{pmatrix}Magnetic\\ Flux\end{pmatrix} = \begin{pmatrix}Magnetic\\ Flux\\ Density\end{pmatrix}\begin{pmatrix}Component\ of\ \vec{A}\\ Normal\ to\ \vec{B}\end{pmatrix}$$

$$\Phi_B = (B)\,(A_\perp)$$

$$\Phi_B = (B)\,(\cos\theta)$$

$$\Phi_B = BA\cos\theta$$

$$\boxed{\Phi_B = \vec{B}.\vec{A}}$$

SPECIAL CLASSES:

(1) POSITIVE FLUX:

If $0° \le \theta < 90°$, flux through the surface is positive. When vector area and magnetic lines.Are parallel i.e. θ=0° and cos0° = 1 then max^m positive flux – is obtained.

(surface is ⊥to magnetic lines.)

$$\Phi_B = B\,A\cos\theta$$

$$= B\,A(1)$$

$$\boxed{\Phi_B = B\,A}$$

(2) NEGATIVE FLUX:

If $90° < \theta \le 180°$, flux through the surface is negative. When vector area and magnetic lines. are anti-parallel i.e.θ = 180° and cos180° = -1 then max^m negative flux – is obtained.(surface is ⊥ to magnetic lines.)

$$\Phi_B = B\,A\cos\theta$$

$$= B\,A\,(-1)$$

$$\boxed{\Phi_B = -\,B\,A}$$

(3) MINIUM (ZERO)FLUX:

When vector area and magnetic lines are perpendicular i.e θ = 90° and cos90° =0, then min^m flux is obtained (surface is || to magnetic lines).

$$\Phi_B = B\,A\cos\theta$$

$$= B\,A\,(0)$$

$$\boxed{\Phi_B = 0}$$

UNITS:

Unit of Φ_B = T.m² = $\frac{N}{A.m}$.m² = $\frac{N.m}{A}$ $\left(\frac{newton - metre}{per\ ampere}\right)$

= $\frac{J}{C}$ = $\frac{J}{C}s$ = v.s $(volt - second)$

= Wb **(WEBER)**

MAGNETIC FLUX DENSITY OR MAGNETIC INDUCTION:

INTRODUCTION:

The direction and magnitude of a magnetic field are indicated by a vector $\vec{B}$, known as **MAGNETIC FLUX DENSITY** or **MAGNETIC INDUCTION**

DEFINITOIN:

"Number of magnetic lines of induction per unit area crossing a surface placed normal to magnetic field is called MAGNETIC FLUX DENSITY or MAGNETIC INDUCTION.

Or

"Magnetic flux per unit area through a surface placed normal to the magnetic field is called MAGNETIC FLUX DENSITY or MAGNETIC INDUCTION."

MATHEMATICAL EXPRESSION:

By definition,

$$\left(\frac{Magnetic}{Flux\ Density}\right) = \frac{Total\ Magnetic\ Flux}{Total\ Area}$$

But Magnetic Flux is given by:

$$\Phi_B = B\,A\cos\theta$$

When lines of induction cross the area normally, then $\theta = 0°$ and $\cos 0° = 1$. Thus,

$$\Phi_B = B\,A$$

$$B = \frac{\Phi_B}{A}$$

UNIT:

Since

$$B = \frac{F}{qvisn\theta}$$

Unit of B = $\frac{N}{C.\frac{m}{s}} = \frac{N}{\frac{C}{s}.m}$

$= \frac{N}{A.m}$ $\left(\frac{\text{newton per ampere}}{per\ metre}\right)$

= T **(TESLA)**

$\frac{Wb}{m^2}$ (waber per metre squared)

MAGNETIC FORCE ON A MOVING CHARGE

INTRODUCTION:

A moving charge produces a magnetic field of its own. If a charge is projected into an applied magnetic field, the two fields interact with each other. Consequently, the moving charge experiences a force of magnetic nature.

MAGNITUDE OF FORCE:

We consider a charge +q projected with velocity $\vec{v}$ into anapplied magnetic field of induction $\vec{B}$ it is found experimentally thatthe force experienced by the charge is directly proportional to

(1) The magnitude of charge *'q'*
(2) The magnitude of velocity *'v'*

(3) The magnitude induction 'B"

(4) The sine of angle 'θ' from $\vec{v}$ to $\vec{B}$

$$F \propto |q|\, v\, B\sin\theta$$

$$F = k\,|q|\, v\, B\sin\theta$$

In SI, the unit of B is so adopted that the proportionality constant '*k*' becomes unity.

$$\boxed{F = |q|\, v\, B\sin\theta}$$

VECTORIAL EXPRESSION

Since $\vec{F}$, $\vec{v}$ and $\vec{B}$, are vectors and 'θ' is the angle from $\vec{v}$ or $\vec{B}$, the force can be expressed as a vector product:

$$\boxed{\vec{F} = q\,(\vec{v} \times \vec{B})}$$

UNIT of "B"

Since
$$B = \frac{F}{qvisn\theta}$$

$$\text{Unit of B} = \frac{N}{C.\frac{m}{s}} = \frac{N}{\frac{C}{s}m}$$

$$= \frac{N}{A.m} \quad \text{(newton per ampere per metre)}$$

$$= T \quad \text{(TESLA)}$$

$$\frac{Wb}{m^2} \quad \text{(waber per metre squared)}$$

The CGS unit is **GAUSS (G),** such that **$1\ T = 10^4\ G$**

DEFINITION OF TESLA:

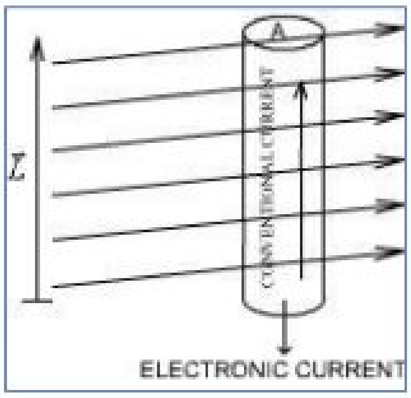
"A unit magnetic field of induction is said to exist at a point where a unit positive charge moving at 1 m/s perpendicular to the magnetic field experience a force of 1 N.

MAGNETIC FORCE ON A STRAIGHT CURRENT-CARRYING CONDUCTOR

INTRODUCTION:

When a straight current-carrying conductor is placed in a magnetic field, force is exerted on the conduction electrons drifting through the conductor. Since the electrons cannot escape sideways, the force on them is transmitted to the conductor.

MATHEMATICAL EXPRESSIONS:



We consider a conductor of length 'L' and cross-sectional area 'A' carrying a current 'I' placed in a uniform magnetic field of induction $\vec{B}$.

The volume of this conductor can be expressed as:

$$V = AL$$

Let 'N' be the total no. of electrons in the wire and 'n' be The no. of electrons per unit volume, then

$$n = \frac{N}{V}$$

$$N = nV$$

$$N = nAL$$

The charge n an electron is –e thus total charge is

$$q = N(-e) = -Ne$$

$$q = -nALe$$

Current in a conductor is due to drift of free electrons but conventionally we consider an equivalent positive charge flowing opposite to electrons i.e

$$q = nALe$$

The magnetic force on charge is given as:

$\vec{F} = e\,(\vec{V} \times \vec{B})$

$\vec{F} = nALe\;(\vec{V} \times \vec{B})$

Let $\hat{a}$ be a unit vector in the direction of $\vec{v}$, then

$\vec{v} = v\hat{a}$

$\vec{F} = nALe\;(v\hat{a} \times \vec{B})$

$\vec{F} = nAve\;(L\hat{a} \times \vec{B})$

If '*t*' is the time taken by charge to cross length '*L*' of the conductor, then

$$v = \frac{L}{t}$$

Current in the conductor is

$$I = \frac{q}{t} = \frac{nALe}{t} = nA\frac{L}{t}e$$

$$I = nAve$$

Thus, we have:

$$\boxed{\vec{F} = I\,(\vec{L} \times \vec{B})}$$

In terms of magnitude,

$$\boxed{\vec{F} = I\,L\,B\sin\theta}$$

Where 'θ' is the angle from $\vec{L}$ to $\vec{B}$.

SPECIAL CASE:

(1) MAXIMUM FORCE:

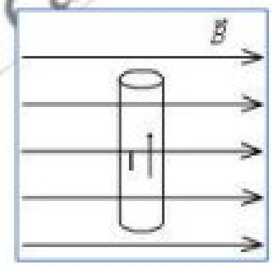
CASE I: When the current in a conductor is perpendicular to $\vec{B}$, i.e

$\theta = 90°$, then $\sin 90° = 1$. Thus,

$F = BIL\sin\theta = BIL(1)$

$$\boxed{F = BIL}$$

Thus, the conductor experience maximum magnetic force.



(2) ZERO FORCE:

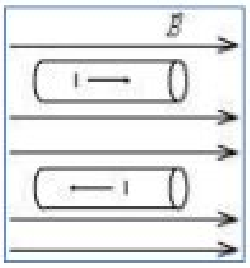
CASE II: When the current in a conductor is parallel to $\vec{B}$ i.e

$\theta = 0°$, or antiparallel to $\vec{B}$ i.e $\theta = 180°$, then

$\sin\theta° = \sin 180° = 0$. Thus,

$F = BIL\sin\theta = BIL(0)$

$$\boxed{F = (0)}$$



(3) CASE III:

When the conductor has no current it experience no magnetic force.

MOTION OF A CHARGE PARTICLE IN A MAGNETIC FIELD:

RADIUS OF CIRCULAR THAJECTORY WHEN CHARGE IS PROJECTED PERPENDICULARLY:

We consider a charge +q projected perpendicularly with velocity $\vec{v}$ into a uniform magnetic field of induction $\vec{B}$. The magnetic force on it is given as:

$$\vec{F_m} = q\,(\vec{v} \times \vec{B}) \quad \text{----①}$$

In magnitude terms, $F_m = |q|\,v\,B\sin\theta$ (Where θ is the angle from $\vec{v}$ to $\vec{B}$)

$$F_m = |q|\,v\,B\sin 90° = |q|\,v\,B(1)$$

$$F_m = |q|\,v\,B \quad \text{----②}$$

Eqn ① shows that this force is always perpendicular to both $\vec{v}$ to $\vec{B}$, while eqn ② reveals constant-magnitude force that is always perpendicular to the charge's motion. This force charges the direction of velocity only and cannot alter the magnitude of velocity (i.e.speed).

Thus, this magnetic force acts as the centripetal force on the charge, and the charge follows a circular trajectory inside the magnetic field. The radius of this circular path is found as:

$$F_m = F_c$$

$$|q|\, v\, B = \frac{mv}{|q|B}$$

$$\boxed{r = \frac{mv}{|q|B}}$$

where 'm' is the mass of the charged particle.

RADIUS OF HELICAL TRAJECTORY WHEN CHARGE IS PROJECTED OBLIQUELY:

We consider a charge +q projected obliquely with velocity $\vec{v}$ into a uniform magnetic field induction $\vec{B}$. The magnetic force on it is given by:

$$\vec{F_m} = q\,(\vec{v} \times \vec{B})$$

The magnitude of this force is

$$F_m = |q|\, v\, B\sin\theta \qquad \text{(Where } \theta \text{ is the angle from } \vec{v} \text{ to } \vec{B}\text{)}$$

$$F_m = |q|(v \sin\theta)B$$

$$F_m = |q| v_\perp B \quad \text{----②}$$

Eqn ② reveals that:

(1) Magnetic force on charged particle is **max^m** if it enters the field perpendicular to $\vec{B}$.

(2) Magnetic force on charged particle is **zero** if it enters field parallel to $\vec{B}$.

Thus, we deduce that the magnetic force acts only on the component of velocity normal to $\vec{B}$ (i.e $v_\perp = v\sin\theta$), while the component of velocity parallel to $\vec{B}$ (i.e $v_\parallel = v\sin\theta$),remains constant. Thus, the Particle follows a helical trajectory.

$$F_m = F_C$$

$$|q| v_\perp B = \frac{m v_\perp^2}{r}$$

$$|q| v \sin\theta\, B = \frac{m(v\sin\theta)^2}{r}$$

$$\boxed{r = \frac{mv\sin\theta}{|q|B}}$$

J.J THOMSON'S EXPERIMENT

(DETERMINATION OF e/m OF AN ELECTRON)

INTRODUCTION:

In 1897, Sir J.J THOMSON succeeded in measuring the charge-to-mass ration $(e/m)$of an electron.

WORKING PRINCIPLE:

When a beam of charged particles is project into a uniform magnetic field perpendicularly, it experiences a deflecting force $\vec{F} = q(\vec{v} \times \vec{B})$ which does not change the magnitude of $\vec{v}$, but continuously changes direction of $\vec{v}$ and makes the beam moves in a circular path. By nothing the deflection of particles,$(e/m)$is calculated.

Experimental apparatus (construction):

J. J. Thomson used a special apparatus for this experiment:

(1) FILAMENT (F):

It is a hollow tungsten filament which produces electrons when heated (due to thermionic emission).

(2) CATHODE / CYLINDER (C):

It is a hollow cylinder at negative potential. It surrounds 'F' to focus electrons along $+x$-axis.

(3) ANODES (A & A'):

A & A' are circular metal plates, each with a hole at its center. A potential difference is applied across them to accelerate and collimate electrons.

(4) HORIZONTAL PLATES (P & P'):

P & P' are horizontal metallic plates. An electric field is produced between them along-y-axis.

(5) HELMHOLTZ COILS:

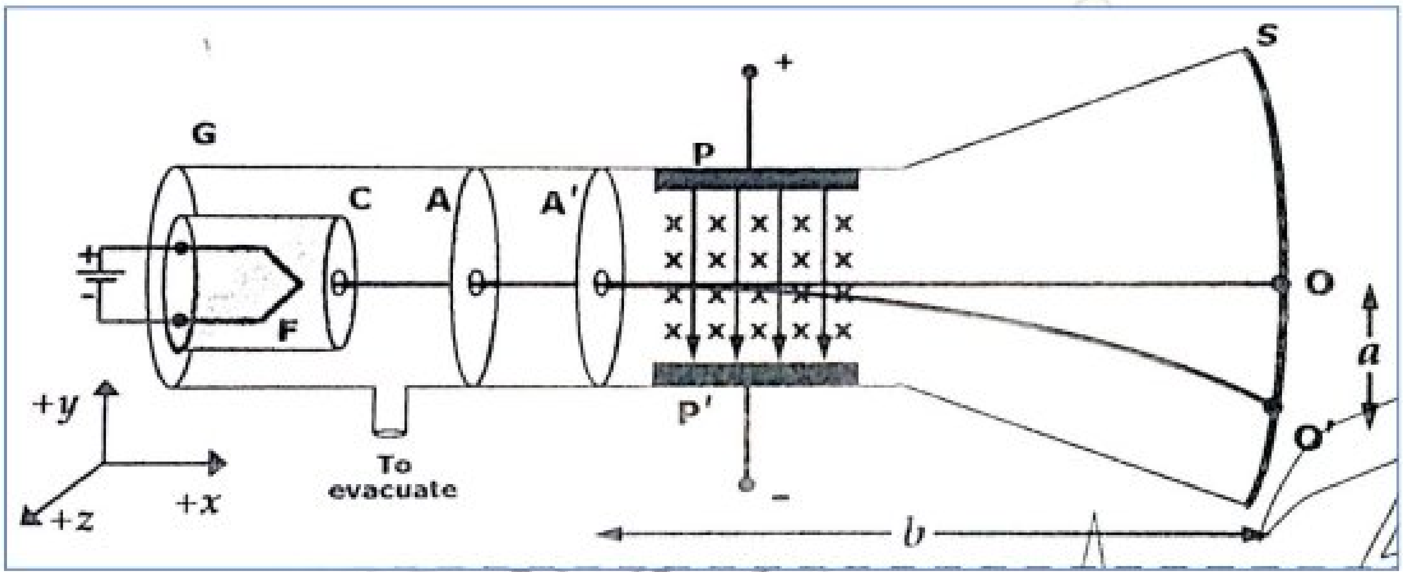
A pair of circular current-carrying coils is used to produce a magnetic field along-z-axis.

(6) FLUORESCENT SCREEN (S):

It is a screen coated with some fluorescent material (e.g.**ZnS**).

(7) GLASS TUBE (G):

The whole assembly is kept in a special evacuated glass tube.



PROCEDURE (WORKING):

(1) An electron beam is produced by heating the filament **F**.

(2) The beam is focused towards the screen by applying negative potential on cylinder **C**.

(3) The beam is accelerated by a potential difference of **1000V b/w** filament **F** and disc **A**.

(4) The beam is further accelerated by a potential difference of 500 V between **A & A**.

(5) After passing through **A;** the beam moves on the screen **S** and forms a light spot at **o**.

(6) A magnetic field $\vec{B}$ is produced along –z-axis in the region between A' and screen **S**. Thus, the electron beam is deflected along $-y$-axis and the light spot shifts from o to o.

(7) An electric field between P and P' is produced along $-y$-axis the light spot shifts from **O** to **O'**. deflected along $+y$-axis and the spot re-shifts from **o'** to **o**.

MATHEMATICAL EXPRESSIONS:

Magnetic force on a moving charge is given by

$$F_m = |q|v_{\perp}\mathbf{B}$$

Here $|q|$=e (for electron)

And θ= 90° (electron beam moves ⊥to magnetic field)

$$F_m = ev\,B\sin 90^\circ = ev\,B\,(1)$$

$$F_m = ev\,B$$

The magnetic force on the electron beam provides the necessary centripetal force, so that the electron beam follows a circular trajectory and the light spot is shifted from 0 to 0′. Thus,

$$F_m = F_C$$

$$evB = \frac{mv^2}{r}$$

$$\boxed{\frac{e}{m} = \frac{v}{Br}}$$

Here 'B' is known.

Thus, to determine the value of $(^e/_m)$ 'v' and 'r' have to be determined.

Determination of velocity:

Method I: (POTENTIAL DIFFERENCE METHOD):

If the accelerating voltage between filament F and disc B is V,. then

(Gain in K.E) = (Loss in Electrical P.E)

$$\frac{1}{2}mv^2 = q_0V \qquad \begin{bmatrix} V = \frac{u}{q_0} \\ u = q_0V \end{bmatrix}$$

$$\frac{1}{2}mv^2 = eV$$

$$v^2 = \frac{2eV}{m}$$

$$v^2 = \sqrt{\frac{2eV}{m}}$$

Putting this value in eqn ①, we get

$$\frac{e}{m} = \frac{\sqrt{\frac{2eV}{m}}}{Br}$$

$$\frac{e^2}{m^2} = \frac{\frac{2eV}{m}}{B^2r^2}$$

$$\frac{e^2}{m^2} = \frac{2eV}{B^2r^2m}$$

$$\boxed{\frac{e}{m} = \frac{2V}{B^2r^2}}$$

The above expression is obtained on the assumption that the initial velocity of electrons emitted from filament is zero, which is not true. Thus the obtained results are only approximately valid.

Method II: (PARTICLE VELOCITY SELECTOR MATHOED):

The electron beam is passed through crossed electric and magnetic fields. The value of $\vec{E}$ is so adjusted that the electrical force along $+y$-axis exactly balance the magnetic force along –y-axis, and the electron beam passes undeflected through this regain to o. Thus,

$$\begin{pmatrix} Magnetic \\ Force \end{pmatrix} = \begin{pmatrix} Electric \\ Force \end{pmatrix}$$

$$F_m = F_e$$

$$|q|v\,Bsin\theta = q_0E \qquad \begin{bmatrix} E = \frac{F_e}{q_0} \\ F_e = q_0E \end{bmatrix}$$

$$v\,B(1) = eE$$
$$v = \frac{E}{B}$$

Putting this value in eqn ①, we get

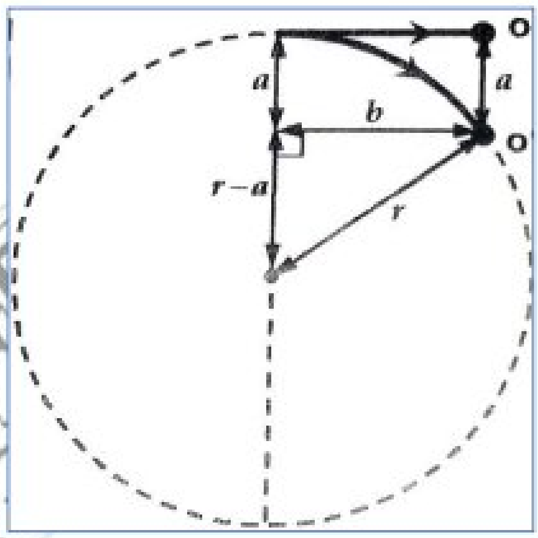
$$\frac{e}{m} = \frac{E/B}{Br}$$
$$\boxed{\frac{e}{m} = \frac{E}{B^2 r}}$$

This method yields more. Accurate results.

DETERMINATION OF RADIUS:

Let 'a' be the shift of the bright spot from o to o', 'b' be the distance from point of deflection of beam to screen, and 'r' be the radius of the circular path followed by electron beam.

Them using Pythagorean Theorem,



$$H^2 = B^2 + P^2$$
$$r^2 = b^2 + (r-a)^2$$
$$r^2 = b^2 + r^2 - 2ra - a^2$$
$$0 = b^2 - 2ra - a^2$$

Since a is very small quantity, its square can be Neglected, thus

$$0 = b^2 - 2ra$$
$$r = b^2/2a$$

FINAL EXPRESSION:

Putting the value of radius eqn ③ ,we get

$$\frac{e}{m} = \frac{E}{B^2\left(\frac{b^2}{2a}\right)}$$
$$\boxed{\frac{e}{m} = \frac{2aE}{B^2 b^2}}$$

CONCLUSIONS:

(1) Thomson's value e/m was **1.7×10^{11} c/kg**. in good agreement with the currents accepted value of **1.758×10^{11} C/kg.**

(2) In 1898, he showed that electron and proton (hydrogen ion) have equal charge.

(3) In 1909. Millikan determined the charge of an electron i.e. **$e = 1.6022\times10^{-19}$ C**. Thus the mass of electron was calculated:

$$m = \frac{1.6022 \times 10^{-19}}{1.758 \times 10^{-11}} = 9.11\times10^{-31}\ \text{kg}$$

THE BIOT- SAVART LAW

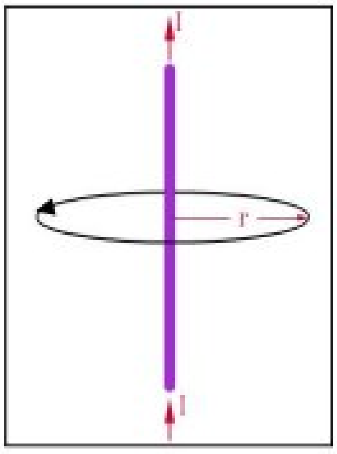
INTRODUCTION:

Biot and **savart** experimentally found the mathematical relation between magnetic induction B due to current-carrying conductor at a nearby point and the current ***I*** through the conductor.

STATEMENT:

"The magnitude of magnetic field of induction due to a straight Current-carrying conductor at a point is directly proportional to twice The value of current through the conductor and inversely proportional to the distance from the conductor

MATHEMATICAL EXPRESSION:



We consider a straight conductor carrying current I through it. The magnetic field of induction due to this conductor is in the form of concentric circles with conductor is given as:

The magnitude of $\vec{B}$ at a distance r from the conductor is given as:

$$B \propto \frac{2I}{r}$$

$$B = \frac{\mu_0 2I}{4\pi r}$$

$$\boxed{B = \frac{\mu_0 I}{2\pi r}}$$

The constant μ_0 is called **PERMEABILITY OF FREE SPACE**. ItIs a measure of crowding of the magnetic field lines in a material. Its value is

$$\mu_0 = 4\pi x10^{-7}\frac{Wb}{A.m} = 4\pi x10^{-7}\frac{T.m}{A} = 4\pi x10^{-7}\frac{H}{m}$$

AMPERE'S CIRCUITAL LAW

INTRODUCTION:

This law is a relation between the tangential component of magnetic field at point on a closed curve and the net current through the area bounded by the curve. It is a very useful means for the determination of magnetic field due to current configuration with simple geometry.

STATEMENT:

"The sum of the products of the tangential components of magnetic field of induction and the length elements of a closed curve (Amperian loop) taken in the magnetic field is μ_0 times the current, Which passes through the area bounded by this curve."

MATHEMATICAL EXPRESSION:

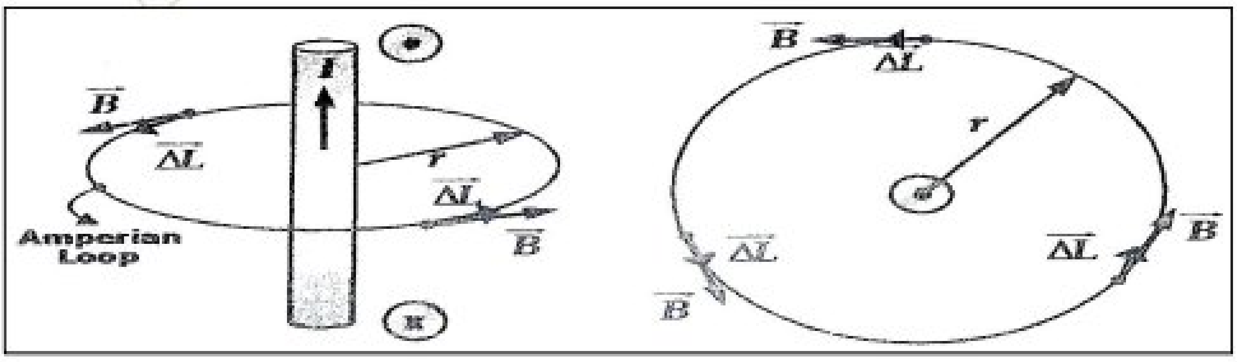
$$\boxed{\sum_{i=1}^{n} (\vec{B}.\vec{\Delta L})_i = \mu_0 (Current\ Enclosed)}$$

The constant μ_0 is called **PERMEABILITY OF FREE SPACE**. It is a measure of crowding of the magnetic field lines in a material.

$$\mu_0 = 4\pi x10^{-7}\frac{Wb}{A.m} = 4\pi x10^{-7}\frac{T.m}{A} = 4\pi x10^{-7}\frac{H}{m}$$

PROOF:

Consider a closed path in the magnetic is divided to elements of length Δl and for each element the quantity $\vec{B}.\vec{\Delta \ell}$ is



determined.

$$\sum \vec{B}.\vec{\Delta\ell} = \vec{B}.\vec{\Delta\ell_1} + \vec{B}.\vec{\Delta\ell_2} + \vec{B}.\vec{\Delta\ell_3} + ... + \vec{B}.\vec{\Delta\ell_n}$$

$$\sum \vec{B}.\vec{\Delta\ell} = \vec{B}.\vec{\Delta\ell_1}\cos\theta + \vec{B}.\vec{\Delta\ell_2}\cos\theta + \vec{B}.\vec{\Delta\ell_3}\cos\theta + ... + \vec{B}.\vec{\Delta\ell_n}\cos\theta$$

Here $\theta = 0^o$, and $\cos 0^o = 1$,

Therefore

$$\sum \vec{B}.\Delta\vec{\ell} = \vec{B}.\overrightarrow{\Delta\ell_1} + \vec{B}.\overrightarrow{\Delta\ell_2} + \vec{B}.\overrightarrow{\Delta\ell_3} + ... + \vec{B}.\overrightarrow{\Delta\ell_n}$$

$$\sum \vec{B}.\Delta\vec{\ell} = \vec{B}(\overrightarrow{\Delta\ell_1} + \overrightarrow{\Delta\ell_2} + \overrightarrow{\Delta\ell_3} + ... + \overrightarrow{\Delta\ell_n})$$

Here $(\overrightarrow{\Delta\ell_1} + \overrightarrow{\Delta\ell_2} + \overrightarrow{\Delta\ell_3} + ... + \overrightarrow{\Delta\ell_n}) = 2\pi r$ **= Circumference**

Therefore

$$\sum \vec{B}.\overrightarrow{\Delta\ell} = B \text{ x } 2\pi r ----------(1)$$

$$\sum \vec{B}.\Delta\vec{\ell} = \frac{\mu_o I}{2\pi r} \text{x} 2\pi r$$

$$\boxed{\sum \vec{B}.\Delta\vec{\ell} = \mu_o I}$$

CONCLUSIONS:

(1) This law is a very useful means for the determination of magnetic field due to a current configuration with simple geometry.

(2) This law is applicable for steady currents passing through any surface, bounded by arbitrary closed paths of any shape (Amperian loop).

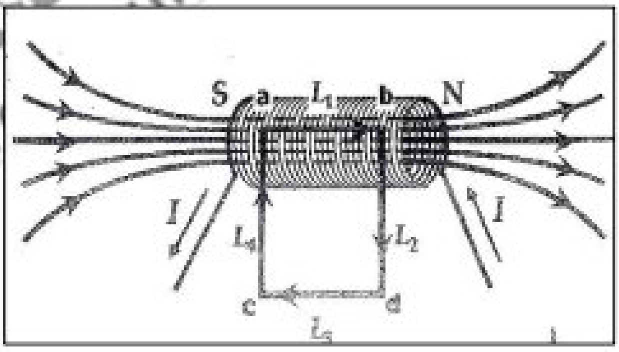
(3) It is useful only for calculating B near symmetric current configurations.

APPLICATIONS OF AMPERE'S LAW

(1) MAGNETIC INDUCTION DUE TO SOLENOID:

DEFINITON:

"A helical coil of long insulated conducting wire with close turns, such that its length is greater than is diameter, is called Solenoid. When current is passed through such a coil, it behaves like a bar magnet."



DETERMINATION OF MAGNETIC INDUCTION:

In order to determine the magnetic indirection inside the solenoid, imagine a rectangular loop abcd with the side 'ab' on the axis. It is divided into four elements $\ell_1, \ell_2, \ell_3 \text{and} \ell_4$.

By Ampere's circuital law

$$\sum \vec{B}.\overrightarrow{\Delta\ell} = \mu_o \text{x Current enclosed}$$

$$B\ell_1 + B\ell_2 + B\ell_3 + B\ell_4 = \mu_o \text{x current elclosed}-----------(1)$$

Since $\ell 2 \text{and} \ell_4$ are perpendicular to the field there B ℓ_2 and B ℓ_4 are zero. Also ℓ_3 is for away from solenoid, Hence effect of field is zero and $B\ell_3 = 0$.

Now equation (1) becomes

$$B\ell_1 = \mu_o \text{x current enclosed}------------(2)$$

Let $n = \frac{\text{No.of turn}}{\text{Length}}$

I = Current in each turn

nI = Current I unit length

Current enclosed = nI ℓ_1

Put current enclosed is equation -------------- (2)

$$B\ell_1 = \mu_o \text{x nI}\ell_1$$

$$\boxed{B = \mu_o \text{nI}}$$

i) Toroidal Field:

A toroid or a circular solenoid is a coil of wire wound on a circular core with close turns.

Let the toroid consist of 'N' closely packed turns and carry a current 'I'.

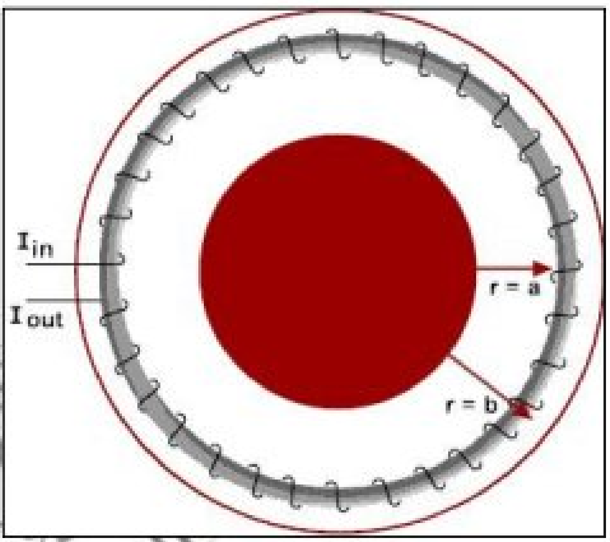
For Curve 1 and 3:

Since No. line of force is touching the curves 1 and 3, therefore B = 0 on both curves 1 and 3.

For Curve 2:

Curve No. 2 is within the core and hence field can be calculated.

By Amere's circuital law:



$$\sum \vec{B}.\overrightarrow{\Delta\ell} = \mu_o \text{x Current enclosed}$$

$$\sum \vec{B}.\overrightarrow{\Delta\ell}\ \cos\theta = \mu_o \text{x Current enclosed}$$

$$\vec{B}\sum \overrightarrow{\Delta\ell} = \mu_o \text{x Current enclosed}$$

$$\vec{B}2\pi r = \mu_o \text{x Current enclosed}$$

Hence NI = Current enclosed.

Now

$$\vec{B}\text{ x }2\pi r = \mu_o \text{NI}$$

$$\boxed{\vec{B} = \frac{\mu_o NI}{2\pi r}}$$

GALVANOMETER

DEFINITION:

"A very sensitive device to detect and measure electric current (or Potential difference) is called GALVANOMETER."

The range of galvanometer to measure current (or potential) is very small up to a few mill amperes (or few millivolts).

TYPES:

The common types of galvanometers are:

(1) Moving-coil Galvanometers
(2) Moving-magnet galvanometers
(3) Moving-Iron galvanometers
(4) Hot-wire galvanometers

MOVING-COIL GALVANOMETERS

TYPES: It is of two kinds:

(1) D'Arsnoval (suspended-Coil) Type
(2) Weston (pivoted Coil) Type

WORKING PRINCIPLE:

"When a coil is placed in a magnetic field and current is passed through it, the coil experiences a deflecting torque." (Motor Principle) The coil continues to rotate until the deflecting couple is balanced by torsion couple. The magnitude of deflection is a measure of current or potential difference.

CONSTRUCTION:

The main components of a moving-coil galvanometer are:

1. FIELD MAGNET:

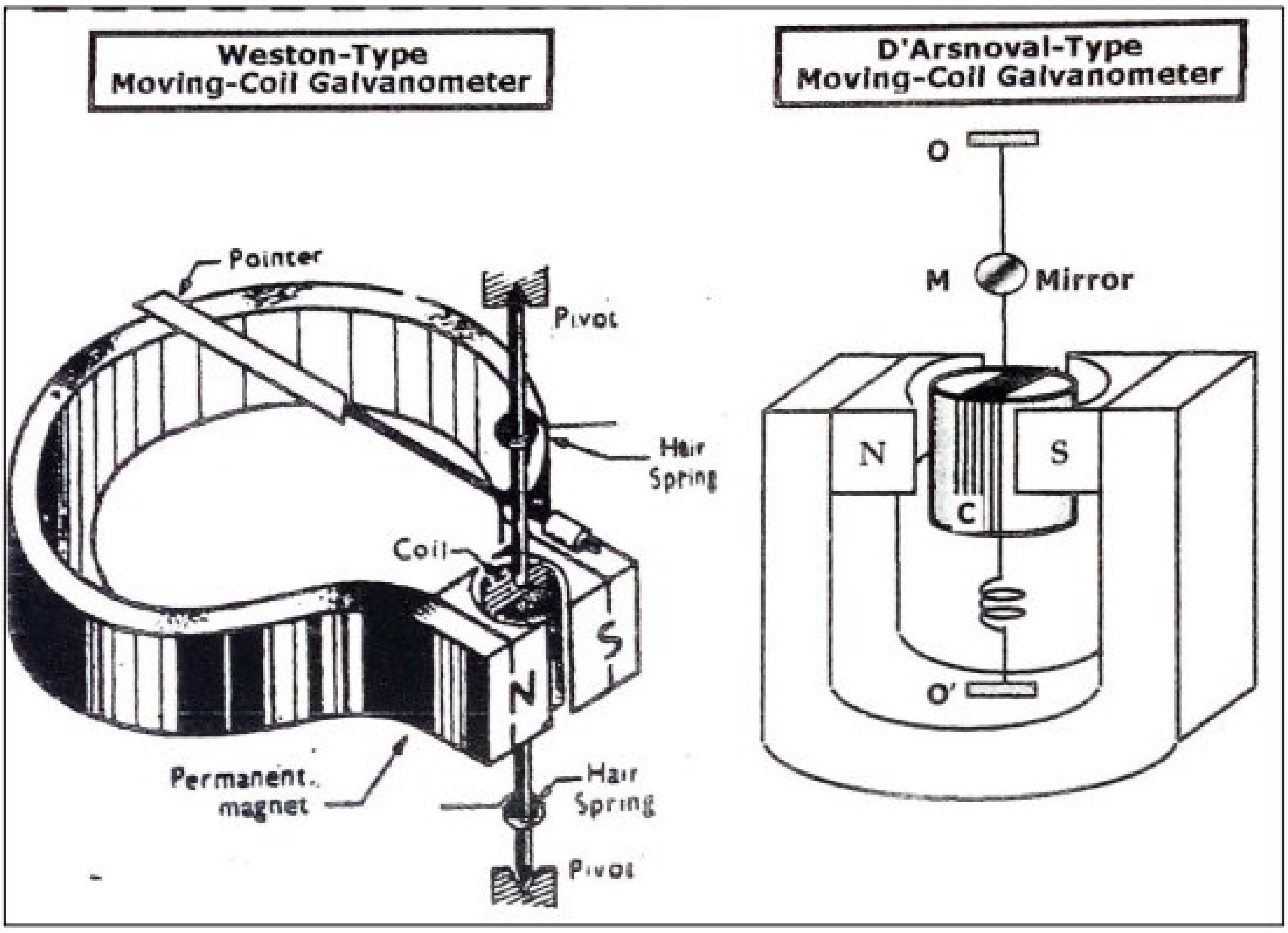
It is a U-shaped magnet, whose pole-pieces are made concave to make magnetic field stronger and radial. It is usually mounted vertically in D'Arsnoval type and fixed horizontally in Weston Type

2. COIL:

The coil is made from a fine enameled (or insulated) copper wire, wound on an aluminum frame.

3. CORE:

A soft-iron cylinder, coaxial with the pole-pieces is placed inside the coil. This ensures the field radial and strong.



THEORY & WORKING:

When current passes through the coil, the experiences a deflecting torque which rotates it.

This torque is given by

$$\begin{pmatrix} Deflecting \\ Torque \end{pmatrix} = \tau_D = BINA\ cos\alpha$$

Where B = *Magnetic Field of Induction*

I = *Current through the coil,*

N = *No of turns in the coil,*

A = *Area of the coil,*

And α = *Angle between* $\vec{B}$ *and plane of the coil*

- In this case the coil is suspended in a radial magnetic field such that the plane of the coil is always parallel to the field. Thus,

$\alpha = 0°$ $\cos\alpha = \cos 0° = 1$

Consequently,

$$\boxed{\tau_D = BINA}$$

As the coil rotates, a twist is produced in the suspension fiber (for D'Arsnoval Type) or one of the hair springs (in Weston Type). Due to elasticity of the fiber/hair-spring another torque is produced opposite to the deflecting torque, which tends to bring the fiber/hair-spring and the coil back to their original position. It is obvious that

$$\begin{pmatrix} \text{ELastic} \\ \text{Torque} \end{pmatrix} \alpha \begin{pmatrix} \text{Angle of} \\ \text{Deflection} \end{pmatrix}$$

i.e $\tau_R \; \alpha \; \theta$

$$\boxed{\tau_R = C\,\theta}$$

Where the **constant of proportionality C** is called **COUPLE PER UNIT TWIST.**

It is a material constant of spring. Mathematically, $C = \frac{\tau_R}{\theta}$

As the twist in the fiber increases, the elastic restoring torque also increases such the that it finally equals the deflecting torque bringing the coil into equilibrium . In this condition,

$$\begin{pmatrix} \text{Deflection} \\ \text{Torque} \end{pmatrix} = \begin{pmatrix} \text{ELastic} \\ \text{Torque} \end{pmatrix}$$

$$BIAN = C\theta$$

$$I = C\theta / BAN$$

for any given coil i-e for Galvanometer C/BAN is constant. Therefore

$$I = Constant(\theta)$$

Thus $I \propto \theta$

For moving-coil galvanometer current is directly proportional to the angle of deflection implying that a linear SCALE is used to measure current.

SENSITIVITY OF A GALVANOMETER:

"The current in microamperes required to produce a unit deflection (1 mm or 1 div) of light spot on a scale placed 1 m from the mirror, is Called SENSITIVITY".

MATHEMATICAL EXPRESSION:

$$S = \frac{I\,(\text{ in } \mu A)}{\theta(\text{in mm or div})}$$

From eqn ①, we have

$$\frac{I}{\theta} = \frac{C}{BNA}$$

Thus, sensitivity can be expressed as:

$$\boxed{S = \frac{C}{BNA}}$$

FACTORS AFFECTING SENSITIVITY:

A galvanometer is considered more sensitive if it gives large deflections for small values of current. This can be achieved by decreasing the value of the factor $\frac{C}{BNA}$

Thus, to make the galvanometer more sensitive:

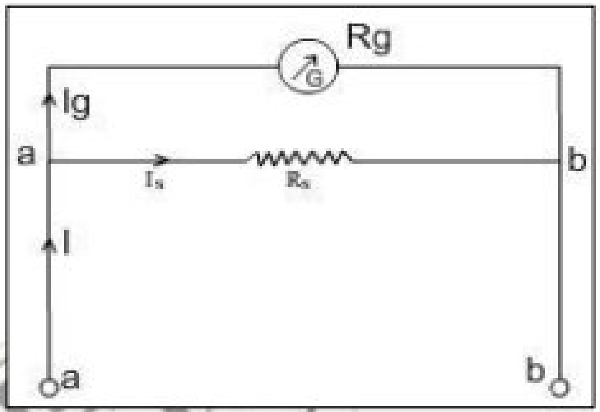
- **i)** **C** should be less. Thus, a long and flat suspension wire is used.
- **ii)** **A** should be large. This increases the device's size.
- **iii)** **N** should be large. This makes the device heavier.
- **iv)** **B** should be high. Strong magnetic field is achieved by using strong magnet and introducing soft-iron core.

AMMETER

"A device used for measuring large amounts of current is called AMMETER."

CONVERSION OF GALVANOMETER INTO AMMETER:

An ammeter is a modified form of galvanometer**. A** galvanometer can be converted into ammeter by connecting a very low resistance called SHUNT RESISTANCE in parallel with the galvanometer's coil.



SHUNT RESISTANCE:

"The low-value resistance connected in parallel with The coil of galvanometer which increases its range to Measure current is called SHUNT RESISTANCE."

PURPOSE OF SHUNT RESISTANCE:

From Ohm's Law we have $I = \frac{V}{R}$ which suggest that a Circuit component draws more current if it has low resistance and vice versa. For this reason, the greater part of current passes through the shunt resistance while only a small part of the total current passes through the galvanometer to measure current.

(1) It increases the rang of the galvanometer ,Thus, the shunt resistance serves two purpose:

(2) It saves the galvanometer from large currents which may burn the galvanometer coil.

VALUE OF SHUNT RESISTANCE (MATHEMATICAL EXPRESSION):

Let I be the current to be measured R_g be the resistance of galvanometer coil, R_s be the shunt resistance, I_g be the current for full-scale deflection of galvanometer, then $I_s = I - I_g$
Must be the current through the shunt resistance.

$$\begin{pmatrix}\text{Potential Drop Across} \\ \text{Galvanometer Coil}\end{pmatrix} = V_g = I_g R_g$$

And
$$\begin{pmatrix}\text{Potential Drop Across} \\ \text{Shunt Resistance}\end{pmatrix} = V_s = I_s R_s = (I - I_g) R_s$$

Since the galvanometer and shunt resistance are in parallel, thus

$$V_g = V_s$$

$$I_g R_g = (I - I_g) R_s$$

$$\boxed{R_s = \frac{I_g}{I - I_g} R_g}$$

CONNECTION IN CIRCUIT:

An ammeter is always connected in series in a circuit so that the total current passing through the circuit should also pass through the ammeter for measurement. If it is connected in parallel only a part of the total current would pass through it, and the ammeter will record this partial current only.

RANGE OF AMMETER:

The range of ammeter can be further increased by decreasing the value of shunt resistance.

VOLTMETER

" A device used for measuring the potential difference Across any two nodes in a circuit called VOLTMETER."

CONVERSION OF GALVANOMETER INTO VOLTMETER:

A voltmeter is modified form of galvanometer. A galvanometer can be converted into voltmeter by connecting a very high resistance called **MULTIPLIER RESISTANCE** in series with the galvanometer's coil.

MULTIPLIER RESISTANCE:

"The high-value resistance connected in series with the coil of galvanometer which increases its range to measure potential is called **MULTIPLIER RESISTANCE**

VALUE OF MULTIPLIER RESISTANCE (MATHEMATICAL EXPRESSION):

Let V be the total potential difference to be measured, R_g be the resistance of galvanometer coil, R_x be the multiplier resistance, and I_g be the current for full-scale deflection of galvanometer.

Now,

$$\begin{pmatrix}\text{Potential Drop Across}\\ \text{Galvanometer Coil}\end{pmatrix} = V_g = I_g R_g$$

$$\begin{pmatrix}\text{Potential Drop Across}\\ \text{Multiplier Resistance}\end{pmatrix} = V_x = I_x R_x = I_g R_x$$

Since the galvanometer and multiplier resistance are in series, thus

$$V = V_g + V_x$$

$$V = I_g R_g + I_g R_x$$

$$V = I_g (R_g + R_x)$$

$$\frac{V}{I_g} = R_g + R_x$$

$$\boxed{R_x = \frac{V}{I_g} - R_g}$$

CONNECTION IN CIRCUIT:

A voltmeter is always connected in parallel in a circuit so that the potential difference across its terminals should be same as the potential difference between the points across which measurement is required.

RANGE OF VOLTMETER:

The range of voltmeter can be further increased by increased by increasing the value of multiplier resistance

19 ELECTROMAGNETIC INDUCTION

ELECTROMAGNETIC INDUCTION

INTRODUCTION:

The relation between electricity and magnetism was discovered in 1819, when OERSTED found that a current-carrying conductor produces a magnetic field of its own. The reverse effect, i.e. magnetism could produce electric current, was investigated enthusiastically but did not yield any results for static magnetic fields.

The effect that electric current could be produced by changing magnetic field was discovered independently, In**1831,** by **Michael FARADAY** in England and by **Joseph HENRY** in the USA. This effect is called **ELECTROMAGNETIC INDUCTION**.

DEFINITION:

"Whenever there is a changing magnetic linked with a circuit, an EMF is induced called INDUCED EMF. This induced ENF produced an Electric current called INDUCED CURRENT, and the phenomena is Called ELECTROMAGNETIC INDUCTION."

MATHODS TO PRODUCE INDUCED EMF:

(1) By relative motion between a loop (or coil) and a magnet
(2) By changing area of a logo of wire in a magnetic field.
(3) By rotating a coil in a magnetic field, called **GENERATOR EFFECT**.
(4) By the making and breaking of current in a coil.
(5) Changing current in a coil induces EMF in neighboring coil, called MUTUAL INDUCTION.
(6) Changing current in a coil induces EMF in itself called SELF INDUCTION.
(7) Relative motion between conductor and magnetic field called MOTIONAL EMF.

FLUX LINKAGE:

"The product of number of turns in a coil and the magnetic flux through it is called FLUX LINKAGE.

MATHEMATICAL EXPRESSION:

If N is the total no. of coil and Φ_B is the magnetic flux through it, then

$$(\textbf{FLUX LINKAGE}) = N\,\Phi_B$$

It is the total flux through coil, and is expressed as sum of fluxes through the individual turns.

UNITS:

Its unit is **WEBER- TURNS** (**Wb-turns**), or simply **WEBER (Wb).**

FARADAY'S LAW OF ELECTROMAGNETIC INDUCTION

INTRODUCTION:

The phenomenon and fundamental law of electromagnetic induction were discovered independently, in **1831,** by **Michael FARADAY** in England and by **Joseph HENRY** in the USA.

STATEMENT:

(1) "An EMF is induced in a circuit, when magnetic flux through the circuit Is changing with time. The EMF lasts as long as the flux is changing And becomes zero as soon as the flux becomes constant."

(2) "The magnitude of the induced EMF is directly proportional to the rate

Of change of magnetic flux linked with the circuit.

MATHEMATICAL EXPRESSION:

Consider a coil of N turns, in which magnetic flux changes by $\Delta \Phi_B$ during time Δt. The average EMF ε induced in the coil is given as:

$$\varepsilon \propto \frac{\Delta \Phi_B}{\Delta t}$$

$$\varepsilon = -N\frac{\Delta \Phi_B}{\Delta t}$$

OR $$\boxed{\varepsilon = -N\frac{d\Phi_B}{dt}}$$

The negative sign is in according with lenz' Law.

LENZ'LAW OF ELECTROMAGNETIC INDUCTION

INTRODUCTION:

The rule for determining the direction of induced EMF and induced current was given by **Herinrich Friedrich LENZ** in **1835**.

STATEMENT:

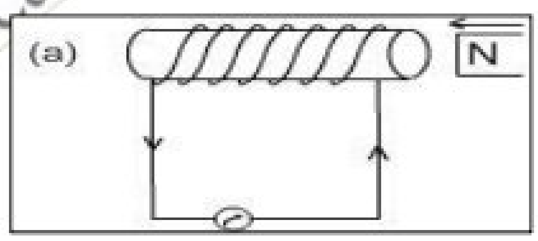
"The direction of the induced current in a conductor is always such that the magnetic field due to it opposes the cause that produces it."

LENZ' LAW IS ELECTROMAGNETIC LAW OF CONSERVATION OF ENERGY:

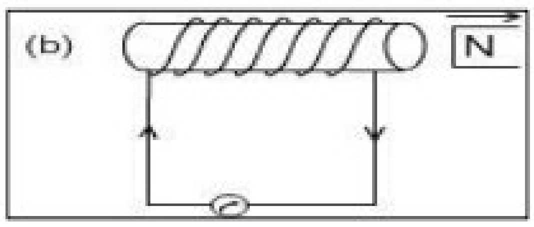
When we push a bar magnet near a coil a currents is induced in the coil which gives rise to its own magnetic field. The induced current and induced magnetic field opposes the push of the bar magnet, so that work has to be done in order to push the bar magnet and induce current in the coil. This is perfectly in accordance with Law of conservation of Energy.

If we had pulled the bar magnet from the coil, the induced current and induced magnetic field would have opposed this pulling effort.

(1) If N-pole of a bar magnet is brought near a coil, induced current appears in this end of the coil, in anti-clockwise direction. Thus this end becomes N-pole and repels the bar magnet.



(2) If N-pole of a bar magnet is moved away from a coil, induced current appears in this end of the coil in **clockwise** direction. Thus, this end becomes S-pole and attracts the bar magnet.



MUTUAL INDUCTION

"When current is changed in a coil (called PRIMARY COIL),it sets up A changing magnetic field which also links with a nearby coil (called SECONDARY COIL).This changing magnetic flux induces as EMF in The secondary coil. This phenomenon is called MUTUAL INDUCTION."

MATHEMATICAL EXPRESSION:

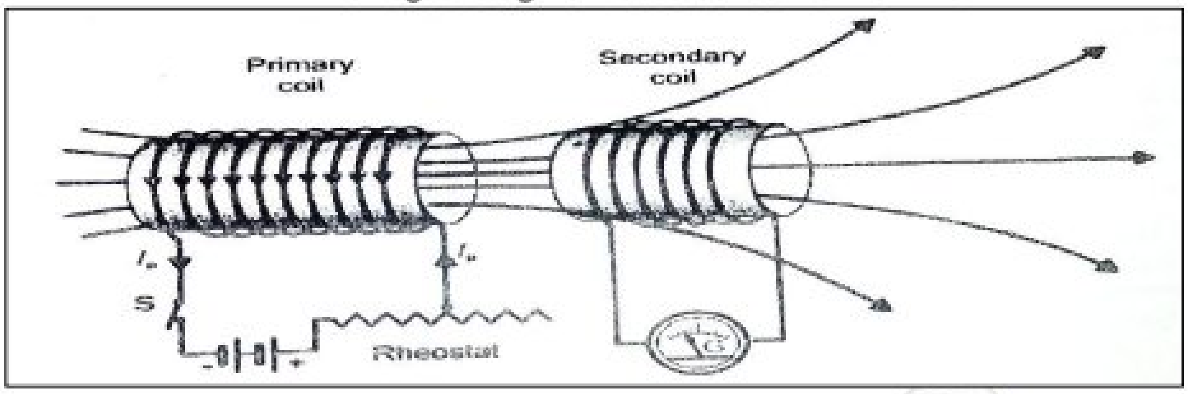
The induced EMF in the secondary coil is directly proportional to rate of change of current in the primary coil:

$$\varepsilon \propto \frac{\Delta I_P}{\Delta t}$$

$$\boxed{\varepsilon = -M\frac{\Delta I_P}{\Delta t}} \quad \text{----①}$$

Here the **proportionality constant** M is called **MUTUAL INDUCTANCE**.

The negative sign is in accordance with Lenz' Law.



According to faraday's Law

$$\varepsilon_s = -N_s\frac{\Delta \Phi_B}{\Delta t}$$

Comparing eqn ① and eqn ② ,

$$-M\frac{\Delta I_P}{\Delta t} = -N_s\frac{\Delta \Phi_B}{\Delta t}$$

$$M\Delta I_P = N_s\frac{\Delta \Phi_B}{\Delta t}$$

$$M\Delta I_P = N_s\Phi_B$$

MUTUAL INDUCTANCE:

"The ability of a pair of coils to induce ENF in one of the coils when Current has changed in the other is called MUTUAL INDUCTANCE. It is The ratio of induced EMF in the secondary coil to rate of change of Current in primary, OR it is the ratio of flux linkage of secondary coil To current in primary coil."

MATHEMATICAL EXPRESSIONS:

From eqn ① , $M = \frac{\varepsilon_s}{\left(\Delta I_P/\Delta t\right)}$

From eqn ②, $M = \frac{N_s\Phi_B}{I_P}$

UNITS: **Unit of M =** $\frac{V}{\frac{A}{S}} = \frac{VS}{A} = \frac{Wb}{A} = H$ **(HENRY)**

DEFINITON OF HENRY:

"The mutual inductance of a pair of coils is 1 H if an EMF of 1 V is induced in one of the coils when current in the other coils has changed by 1 A in 1 s."

FACTORS AFFECTING MUTUAL INDUCTANCE:

(1) Cross-sectional areas of the coils
(2) No. of turns of the coils
(3) Distance between the coils
(4) Permeability of the cores

APPLICATIONS:

(1) Ignition coil of automobiles
(2) Transformer
(3) Induction coil
(4) Induction furnace
(5) Electromagnetic machines

SELF INDUCTION

DEFINITION:

"When current is changed in a coil, it sets up a changing magnetic field. This changing magnetic flux induces an EMF in the coil itself. This phenomenon is called SELF INDUCTION."

BACK EMF:

"According to Lenz' Law, the induced EMF in SELF INDUCTION opposes the Change that has induced it and is there force referred to as BACK EMF.

INDUCTION:

"The dedicated device used in circuits to produce back EMF is called INDUCTOR" CIRCULT

MATHEMATICAL EXPRESSIONS:

The induced EMF in a coil is directly proportional to the rateof change of current in it:

$$\varepsilon_s - \frac{\Delta I}{\Delta t}$$

$$\boxed{\varepsilon_s = -L\frac{\Delta I}{\Delta t}} \quad \text{----①}$$

Here the **proportionality constant** L is called **SELFINDUCTANCE**. The negative sign is in accordance with lenz' law.

According to faraday's Law,

$$\varepsilon_s = -N\frac{\Delta\,\Phi_B}{\Delta t}$$

Comparing eqn ① and eqn ②,

$$-L\frac{\Delta I}{\Delta t} = -N\frac{\Delta\,\Phi_B}{\Delta t}$$

$$L\,\Delta I = N\Delta\,\Phi_B$$

OR $$\boxed{LI = N\Delta\Phi_B}$$

SELF INDUCTANCE:

"The ability of a coil to induce back EMF in itself is called SELF INDUCTION it is the ration of induced EMF to rate of change of current In coil, OR it the ration of flux linkage to change of current in coil."

From eqn ① , $L = -\frac{\varepsilon}{(\Delta I/\Delta t)}$

From eqn ②, $L = \frac{N\,\Delta\,\Phi_B}{\Delta I}$

UNITS: **Unit of L =** $\frac{V}{A/S} = \frac{V.S}{A} = \frac{Wb}{A} = H$ **(HENRY)**

FACTORS AFFECTING SELF INDUCTANCE:

(1) Cross-sectional areas of the coils
(2) No. of turns of the coils
(3) Permeability of the cores

APPLICATIONS:

(1) Regular of fans

(2) Choke for fluorescent tube

(3) Choke for welding plant

NON-INDUCTIVE WINDING

"A wire doubled-back on itself before being coiled up, is called NON-Inductive COIL and the scheme is called NON-INDUCTIVE WINDING."

MOTIONAL EMF

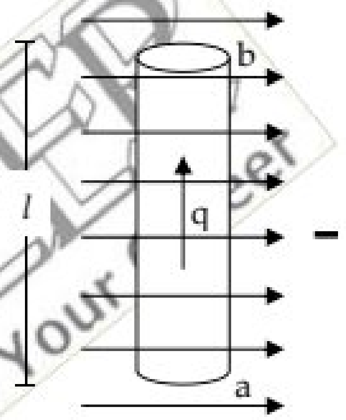
DEFINITION:

"When a conductor is moved across a magnetic field, an EMF is Induced across its ends. This dynamically induced EMF is called MOTIONAL EMF.

MATHEMATICAL EXPRESSION:

Consider a wire of length 'ℓ' is moving across the magnetic field of induction 'B' with the velocity 'v' as shown in figure

The voltage appears across the conductor can be calculated by;



$$V = \frac{Work}{q}$$

$$V = \frac{Fd}{q}$$

$$V = \frac{qVB\sin\theta.\ell}{q}$$

$$V = vB\ell\sin\theta$$

If the conductor in moving perpendicular to the field, then $\theta = 90^\circ$ and $\sin 90^\circ = 1$

$$\boxed{V = vB\ell}$$

TRANSFORMER

DEFINITION:

"The device that transfers electrical energy from one circuit to another Circuit without electrical connection, and converts alternating current at High voltage into low voltage or vice versa, is called TRANSFORMER

PRINCIPLE OF WORKING:

"A transformer works on the principle of mutual induction i.e. a changing current in the primary coil induces an EMF in the secondary coil".

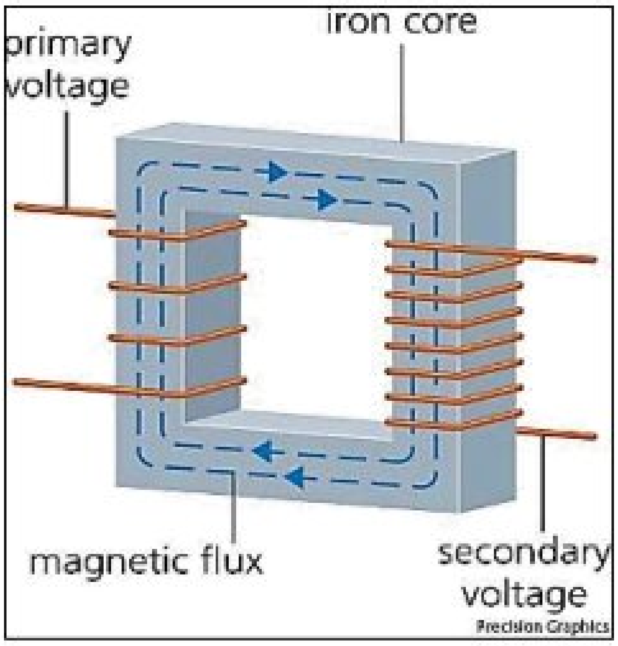
CONSTRUCTION (STRUCTURE):

It consists of rectangular core of iron (Iron Frame), in which two separate coils of copper wire are wound on the core. The coil which is given the current or input is called primary coil, and the coil in which emf is produced and current is supplied to the external circuit is called secondary coil and it is for the output.

TYPES:

Transformers are of two types.

(i) Step up transformer
(ii) Step down transformer.



(i)**STEP – UP TRANSFORMER:**

In it the number of turns of primary coil is less than the number of turns of secondary coil. In this transformer the rate of change of flux in secondary coil is greater than the primary coil.

(ii)**SETP – DOWN TRANSFORMER:**

In it the number of turns of primary coil (N_P) is greater than the number of turns of secondary coil (N_S). In this transformer the rate of change of flux is primary coil is greater as compared to secondary coil.

WORKING:

When voltage is supplied to the primary coil then due to current I_P in primary coil magnetic field produces around the coil. Because the supplied current is A.C which changes every time, due to which magnetic field change and magnetic flux also change. An opposing EMF induces in the primary which is equal to the supplied potential. The second coil is near to the primary coil, therefore emf will be induces due to mutual induction.

MATHEMATICAL PROCESS:

The induced emf in the primary coil will be

$$E_P = -N_P \Delta\phi/\Delta t \text{ ------(1)}$$

and the induced emf in the secondary coil will be

$$E_S = -N_S \Delta\phi/\Delta t \text{ ------(2)}$$

Dividing equation (1) by equation (2)

$$\frac{E_S}{E_P} = \frac{+N_S \Delta\phi/\Delta t}{+N_P \Delta\phi/\Delta t}$$

$$E_S/E_P = N_S/N_P$$

or $$V_S/V_P = N_S/N_P$$

EFFICIENCY OF TRANSFORMER:

The ratio between the power output and input is called Efficiency.

$$\therefore \quad Efficiency = \frac{Power\ output}{Power\ Input}$$

If the Efficiency of the transformer is 100% i-e it is ideal, then

Power output = Power input ------ (A)

But $P = VI$

Or $P = EI$

$\therefore \quad Input\ Power = P_P = E_P I_P$

$Output\ Power = P_S = E_S I_S$

$\therefore$ According to equation no. (1)

$$E_S I_S = E_P I_P$$

$$\frac{E_S}{E_P} = \frac{I_P}{I_S}$$

It means that if $E_S > E_P$ then $I_S < I_P$.

USES:

(i) Step – down transformer is used decreases the high voltage to 220 volt.

(ii) Step – up transformer are used to send electricity up to long distance. Because is secondary coil, therefore less of power is less in transformer line.

(iii) Step down transformer are used in Bell, Radio and telephone extra.

LOSSES IN TRANSFORMERS:

A transformer has no moving parts, so there are no frictional or winding losses however there are four common losses in transformers:

(1) COPPER LOSSES OR I^2 R LOSSES:

Heat is produced in the primary and secondary winding due to joule's heating effect. The arising power losses are given as **$P = I^2 R$**.

These losses are reduced by using thick copper wires (of proper gauge).

(2) IRON LOSSES OR EDDY-CURRENT LOSSES:

The core is a solid conductor currents are induced in the core due to changing magnetic flux, called **EDDY CURRENTS**. These currents produce their own flux opposite to coils' fl;ux, which results in heating of the core. These losses are minimized by using thin sheets of soft iron in the form of laminations, bolted together. He high resistance between laminations greatly reduces the eddy currents and their heating effect.

(3) HYSTERESIS LOSSES:

When magnetization in the core reverses its direction, some energy is wasted called **HYSTERESIS LOSS**. It also produces heating in the core.

This is reduced by using core of very soft iron (poem-alloy or stalloy), which is spontaneously magnetized and demagnetized.

(4) FLUX LEAKAGE:

Some of the flux associated with the primary coil does not link with the secondary, as flux is not confined entirely to the core rather flux is returned through air.

To reduce this leakage, the secondary coil must be wound over the primary coil.

DC MOTOR

DEFINITION:

"An electromechanical device which converts electrical energy into Mechanical energy is called DC MOTOR."

PRINCIPLE:

"when a coil is placed in a magnetic field and current is passed through it, the coil experiences a deflecting torque."(Motor Principle)

CONSTRUCTION:

(1) Field magnet:
It is permanent strong magnet with concave pole-places to produce a radial magnetic field.

(2) ARMATURE:
A coil of several rectangular turns is wound on a soft-iron, cylindrical core. The coil and the core are collectively called ARMATURE. It can rotate (on ball bearings) about an axis passing through its plane longitudinally.

(3) COMMENTATOR:
A split ring of copper is used whose two halves are insulated from each other and joined to the end of armature. It has a number of sections corresponding to each coil.

(4) COLLECTING BRUSHES:
Two carbon rushes remain pressed against each of the commutator split rings to conduct current from a DC source (battery) to the coil, such that change-over of their contact takes place from one split ring to the other and direction of current reverses.

WORKING:

(1) When a clockwise current passesThrough a coil, it experiences a Moment of couple r = BINA cosα,Which rotates the coil in anticlockwise direction .
(2) The torque becomes zero when the face of the coil becomes perpendicular to the field. At this moment inertiacarries the coil beyond this position.
(3) To rotate the coil in anticlockwiseDirection, the current in the coil mustbe in clockwise direction. This is doneBy a commutator, which reverses theCurrent at proper time.

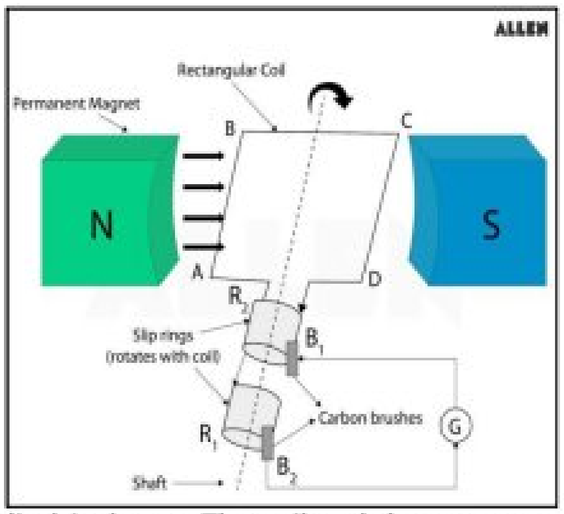
AC GENERATOR

DEFINITION:

"A device that converts mechanical energy into electrical energy Such that it produces alternating EMF and alternating current, is called AC GENERATOR

PRINCIPLE:

Whenever magnetic flux linked with a coil is changed (by rotating a coil in a magnetic field), an EMF is induced in the coil. This phenomenon is called **Electromagnetic Induction**.



Construction:

(1) FIELD MAGNET:
It is a permanent strong magnet with concave pole-places To produce a radial magnetic field.

(2) ARMATURE:
A coil of several rectangular turns is wound on a soft-iron, cylindrical core. The coil and the core are collectively called ARMATURE.

(3) SLIP RINGS:
The ends of the coil are joined to two copper rings fixed On the axle

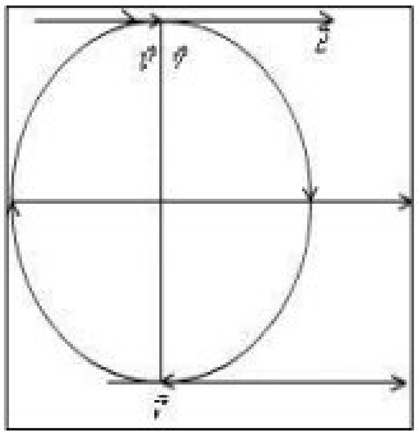
(4) COLLECTING BRUSHES:

Two carbon rushes remain pressed against each of thering to conduct current to the external circuit.

WORKING:

When a coil is moved in a magnetic field then magnetic flux changes and motional emf is produced.

(i) In the first one fourth cycle when the side of coil $\vec{l}$ moves then the angle between $\vec{B}$ and $\vec{V}$ increases form $0°$ **to** $90°$. Therefore the value of emf increase form o to maximum (+ve)



(ii) In 2nd one fourth cycle then angle between $\vec{B}$ and $\vec{V}$ increases form $90°$ **to** $180°$. Therefore, the value of emf decreases from Maximum to zero.

(iii) In the 3rd one fourth cycle the angle between $\vec{B}$ and $\vec{V}$ increases from $180°$ to $270°$. Therefore, the value of emf decreases from zero to negative (Minimum).

(iv) In th e4th one fourth cycle he angle between $\vec{B}$ and $\vec{V}$ increases form $270°$ to $360°$. Therefore the value of emf increases from minimum –ve to zero.

In this way one cycle completes.

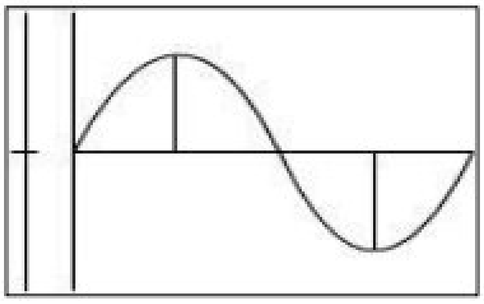
So, **the emf produced in the Generator is +ve in half cycle and –ve in other half cycle i-e. in complete cycle the emf once +ve and once –ve.**

Because, the current change its direction again and again, therefore, it is called A.C.

FORMULA:

A coil which has length "L" is moving in a magnetic field "B" with velocity "V", then the emf produced will be

$$E = VBL\sin\theta$$



due to both sides of the coil

$$E = 2VBL\sin\theta$$

if the coil consists of N turns, then

$$E = 2NVBL\sin\theta$$

but the coil is moving in a circle with angular velocity "W"

$\therefore$ $V = rW$

so, $E = 2NrWBL\sin\theta$

but $r = b/2$ (where b is width of coil)

$\therefore$ $E = 2N\frac{b}{2}WBL\sin\theta$

$E = BNbLW\sin\theta$

but $L \times b = A$ (Area)

$\therefore$ $E = BNAW\sin\theta$ ------ (1)

the value of emf wll be maximum if $\theta = 90°$, $\therefore \sin 90° = 1$

$\therefore$ $E = BNAW$

or $E_{max} = V_0 = NWAB$

Thus, according to equation (1)

$$E = V_0 \sin\theta$$

but $\theta = Wt$

$\therefore$ $E = V_0 \sin Wt$

and $W = 2\pi f$

$\therefore$ $E = V_0 \sin 2\pi ft$ (In the form of frequency)

or $E = E_0 \sin 2\pi ft$

USES:

This Generator is usually used in automobiles, motorcycles and motor boats, which is used in their ignition system.

EFFICIENCY:

The efficiency of Generator in more better, when its Armature is at rest and magnet rotate around it. The rotating magnet is called **ROTOR** and Armature is called **STATOR.**

DC GENERATOR

DEFINITON:

"A device that converts mechanical energy into electrical energy, such that t produces direct EMF and direct EMF and direct current, is called DG GENERATOR.

Principle:

Whenever magnetic flux linked with a coil is changed (by rotating a coil a magnetic field),an EMF is induced in the coil. This phenomenon is called **Electromagnetic Induction.**

CONSTRUCTION:

(1) FIELD MAGNET:

It is a permanent strong magnet with concave pole-places to produce a radial magnetic field.

(2) ARMATURE:

A coil of several rectangular turns is wound on a soft-iron, cylindrical core.The coil and the core are collectively called ARMATURE. It can rotate (on ball bearings)about an axis passing through its plane longitudinally.

(3) COMMUTATOR:

A split ring of copper is used whose insulated from each other and joined to the end of armature. It has a number of sections corresponding to each coil.

(4) COLLECTINGBURSHES:

Two carbon brushes remain passed against each of the commutator split rings commutator split rings to conduct current to the external circuit such that change-over of their contact takes place from one split ring to the other split ring to the other during rotation.

WORKING:

(1) When the coil rotates an alternating EMF is produced but at the instant the EMF reverses its direction the two halves of the commutator exchange their positions, so that the EMF in the external circuit remains unchanged.

(2) Although the current is unidirectional, but it fluctuates from zero to maximum, called **PULSATING DC**.

(3) To obtain a steady current, a number of coils are mounted around armature at different angles and commutator is divided into corresponding number of segment. This provides steady direct current.

24 RELATIVITY

FRAME OF REFERENCE

INTRODUCTION:

Quantities like displacement, velocity and acceleration are always measured with respect to a fixed point in space. The most commonly used reference point is the origin of the rectangular Cartesian system, and the set of three coordinate axes is called **FRAME OF REFERENCE**.

DEFINITION:

"A region of space expressed as a set of three mutually perpendicular axes, is known as FRAME OF REFERENCE."

Classification:

(1) INERTIAL FRAME OF REFERENCE:

DEFINITION:

"A frame at rest or moving with uniform velocity, in which Newton's 1st Law holds true, is called INERTIAL FRAME OF REFERENCE.

EXAMPLES:

- A bus moving with uniform velocity
- A train compartment moving uniform velocity

(2) NON-INERTIAL (ACCELERATED) FRAME OF REFERENCE:

DEFINITION:

"A frame moving with non-uniform velocity is called NON-INERTIAL FRAME OF REFERENCE."

- A bus moving with increasing/decreasing velocity
- A train compartment moving on a circular track

THEORY OF RELATIVITY

INTRODUCTION:

A 25-year old German-born Physicist **ALBERT EINSTEIN** proposed the revolutionary Theory of Relativity, while working as a **clerk in Switzerland**. It was publicized in **two parts:**

SPECIAL THEORY OF RELATIVITY:

The first part was published in 1905. It deals with inertial frames of reference, i.e frames either at rest or moving with uniform velocity.

GENERAL THEORY OF RELATIVITY:

The second part, dealing with non-inertial frames, was publicized in 1915. It deals with the physics of strong gravity, because an accelerated frame is equivalent to a frame in gravitational field.

SPECIAL THEORY OF RELATIVITY

POSTULATES:

In 1905, Einstein based the special theory of Relativity on two postulates.

(1) PRINCIPLE OF RELATIVITY:

"The laws of physics are the same in all inertial frames of reference, including Newtonian Laws of motion & Maxwell's Electromagnetic Equations."

(2) CONSTANCY OF THE SPEED OF LIGHT:

"The speed of light in free space measured in any inertial frame of reference always has the same value c, irrespective of how fast the source of light and the observer are moving relative to each other.

CONSEQUENCES OF SPECIAL THEORY OF RELATIVITY:

The important consequences of the theory of relativity are as under.

(1) Mass Increment:

According to special theory, mass of an object is not an absolute quantity rather its value depends upon the frame of the observer.

Rest Mass

The mass of an object measured in a stationary frame w.r.t the object, is called **REST MASS** or **PROPER MASS**. It is denoted by $\mathbf{m_0}$.

RELATIVISTIC MASS:

The mass of an object, measured in a frame moving with relative velocity v w.r.t the object, is called **RELATIVISTIC MASS**. It is denoted by m.

The Rest and Relativistic masses are related as:

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

The above equation reveals that $m > m_0$, thus mass of an object appears to increases when measured by an observer moving relative to the object.

(2) LENGTH CONTRACTION:

According to special theory, length of an object is not an absolute quantity rather its value depends upon the frame of the observer.

PROPER LENGTH:

The length of an object, measured in astationary frame w.r.t the object is called **REST LENGTH or PROPER LENGTH.** It is donated by I_0.

RELATIVISTIC LENGTH:

The length of an object, measured in a frame moving with relative velocity v w.r.t the object, is called **RELATIVITY LENGTH.** It is denoted I.

The proper and relativistic length are related as:

$$L = L_0\sqrt{1-\frac{v^2}{c^2}}$$

The above equation revels that $L<L_0$, thus an object appears to contract when measured by an observer moving relative to the object. Contraction is measured only in that dimension of object that is along the direction of motion.

(3) TIME DILATION:

According to special theory, time interval between two events is not an absolute quantity rather is value depends upon the frame of the observer.

PROPER TIME:

The time interval of two events, measured in a stationary frame w.r.t the events, is called **REST TIMR** or **PROPER TIME**. It is denoted by t_0.

RELATIVISTIC TIME:

The time interval of two events, measured in a frame moving with relative velocity v w.r.t. the events, is called **RELATIVISTIC TIME**. It is denoted by t.

The two are related as:

$$t = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

The above equation reveals that $t>t_0$ thus the time interval between two events appears to be dilated when measured by an observer moving relative to the events. In other words moving clocks run slow.

(4) Mass energy relation:

REST-MASS ENERGY:

According to special theory, a body at rest has a definite amount of energy called REST MASS **ENERGY** E_0, given as

$$E_0 = m_0 c^2$$

Where m_0 is the rest mass

RELATIVISTIC ENERGY:

When a body moves with relativistic speed, it has increased relativistic mass m and its **RELATIVISTIC ENERGY** is given by.

$$E = m c^2$$

The difference of relativistic energy and rest-mass energy appears as kinetic energy of body,i.e

$$K=E-E_0$$

$$K= mc^2 - m_0 c^2$$

$$K= (m - m_0)c^2$$

This indicates that mass and energy are inter convertible.

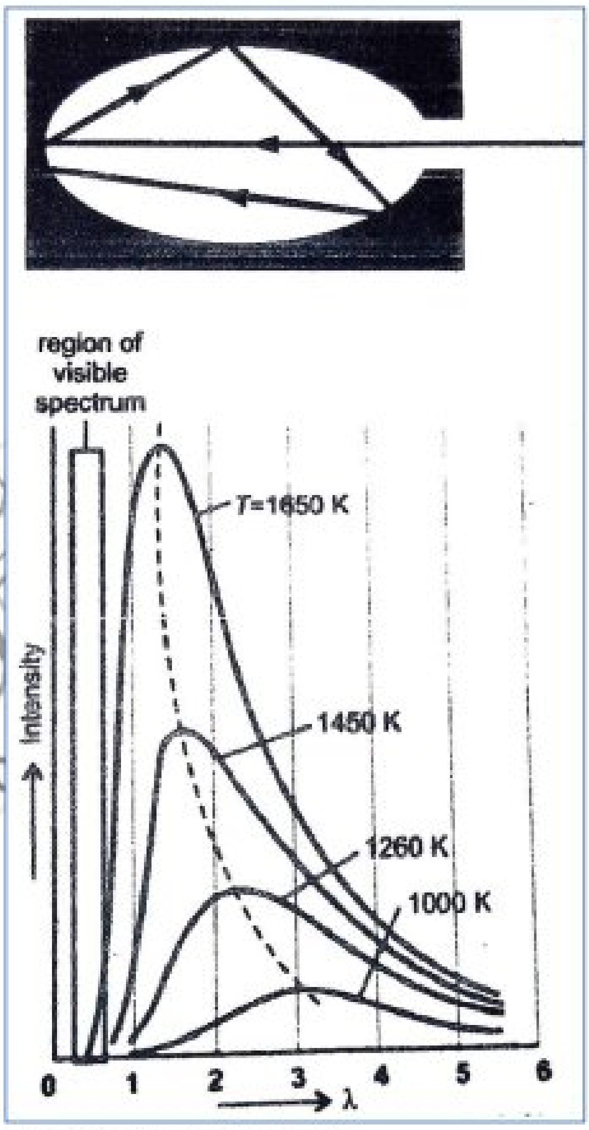
25 QUANTUM PHYSICS

BLACK BODY

DEFINITION:

"An object which can observe all the radiations failing on it, is called Black BODY."

The closest approximation is a hollow sphere of metal painted black inside with a fine hole in it. Any radiation entering the hole of the cavity is absorbed by multiple reflections inside and none comes out, hence the hole in the cavity acts as the Black Body.



Characteristics:

(1) The black body is a perfect absorber at Relatively low temperatures.

(2) It is a perfect emitter at relatively high Temperatures.

(3) As temperature increases the hole turns Red, then yellow, and finally white.

BLACK-BODY RADIATIONS

"A black body is a perfect absorber, and at the same time it is nearly a perfect emitter. When a black body is heated to high temperatures, energy radiations areemitted out of its fine hole, called BLACK- BODY RADIATIONS or CAVITY RADIATIONS or TEMPERATURE RADIATIONS."

Characteristics:

(1) The wavelength of radiations does not depend upon the nature of material of black body.

(2) The wavelength of radiations depends upon temperature of the black body.

(3) They consist of all-types of radiations, comprising continuous distribution of wavelength from infrared, visible and ultraviolet radiations.

(4) As temperature rises, the monochromatic emissive power E_λ (i.e the radiant energy emitted per second per unit wavelength range) for each band of wavelength increases.

(5) At each temperature, the emissive power is max^m for a certain wavelength $\lambda_{\max}$

LAWS OF BLACK-BODY RADIATIONS:

Following laws govern the radiations of black body.

(1) WEIN'S DISPLACEMENT LAW:

STATEMENT:

"The wavelength $\lambda_{\max}$,at which maximum energy is emitted, shifts towards shorter wavelengths as temperature of cavity increases."

MATHEMATICAL EXPRESSIONS:

$$\lambda_{\max} \propto \frac{1}{T}$$

$$\lambda_{\max} = \begin{pmatrix} wein's \\ constant \end{pmatrix} x \frac{1}{T}$$

$$\boxed{\lambda_{\max} \, x \, T = \begin{pmatrix} wein's \\ constant \end{pmatrix}}$$

PROS AND CONS:

(1) The result in agreement with the common observation that a while hot furnace is hotter than a red one.

(2) This law is valid in regions less than $\lambda_{\max}$ only, thus it fails to predict energy distribution over the entire curve at all temperatures.

(2) Stefan's Law:

STATEMENT:

"The total energy of all wavelength radiated per second per unit surface area is proportional to the fourth power of absolute temperature."

MATHEMATICAL EXPRESSIONS:

$$E \propto T^4$$

$$\boxed{E = \sigma T^4}$$

Where σ is called **STEFAN-BOLTZMANN CONTANT**

PROS AND CONS:

(1) The area under the graph of emissive power E and wavelength λ represents total rate of emission from the black body.

(2) It does not succeed to explain energy distribution at all temperature, like Wein's Law.

(3) RAYLEIGH-JEAN's LAW:

INTRODUCTION:

Both Wien's Law and Stefan's Law failed to predict energy distribution over the entire curve at all temperatures, thus Rayleigh and jean proposed their formula in 1899.

ASSUMPTIONS:

(1) Radiations are emitted by a large number of atomic oscillators.

(2) Each mole of vibration is associated with thermal energy KT, where K is **BOLTZMANN CONSTANT**.

STATEMENT:

"The energy associated with a particular wavelength is inversely proportional to the fourth power of wavelength."

MATHEMATICAL EXPRESSIONS:

The obtained the following relation:

$$E_\lambda = \frac{8\pi kT}{\lambda^4}$$

At a certain temperature,

$$E_\lambda = \frac{constant}{\lambda^4}$$

$$\boxed{E_\lambda \propto \frac{1}{\lambda^4}}$$

PROS AND CONS:

(1) The graph from this law fits well with the experimental graph at longer wavelengths, but fails at short wavelengths.
(2) For wavelengths shorter than λ_{max} the total energy tends to infinity.But experimental contradiction is called **ULTRAVIOLET CATASTROPHE**.
(3) The failure of Rayleigh-Jean's Law presented a theoretical crisis in physics.

(4) PLANCK'S QUANTUM THEORY OF RADIATION:

INTRODUCTION:

In **1900**, a German physicist Max Planck presented the famous Quantum theory to solve the dilemma of Black-Body Radiations.

STATEMENT:

"Hot bodies radiate energy in discrete amount, each of which is called a QUANTUM of energy. The energy of each quantum is directly proportional to the frequency of radiations."

MATHEMATICAL EXPRESSIONS:

$$E \propto \nu$$
$$E = h\nu$$
$$E = \frac{hc}{\lambda}$$

Where h is **PLANCK'S CONSTANT. Its value is** 6.625x10^{-34} J.s.

The total energy radiated in a wave containing n photons is given by

$$E = nh\nu$$

PROS:

(1) Max. Planck's theoretical graph fits excellently with experiment graph at all temperature
(2) Plank's Law is true for both short and long wavelengths.

EINSTEIN'S NOTION OF PHOTONS:

Albert Einstein extended Planck's idea and postulated that packets of energy (quanta) are integral part of all electromagnetic radiations. He called these discrete bundles as **PHOTONS**.

CONCLUSION:

Radiations have particle nature in exhibiting certain phenomena.

PHOTON

DEFINITION:

"Discrete packets of electromagnetic energy and carries of electromagnetic forces, are called PHOTONS (or QUANTA)."

CHARACTERISTICS:

(1) **SPEED:**

Photos may have different energies but they always moves with speed c=3x10^{8} m/s in vacuum .

(2) **ENERGY CONTENT:**

According to Planck's Quantum Theory, energy of a photon is directly proportional to frequency of electromagnetic waves i.e.

$$E \propto \nu$$
$$E = h\nu$$

Where h is **PLANCK'S CONSTANT. Its value is 6.625x10^{-34} J.s.**

(3) MASS:

Rest mass of a photon is zero i.e. it is a massless particle. It exists due to its motion.

$$E = m c^2$$

& $$E = h \nu$$

$$mc^2 = h \nu$$

$$\boxed{m = \frac{h\nu}{c^2}}$$

It is clear from the above equation that m approaches zero as c^2 is very large quantity. Thus, photon is the lightest particle. The rest mass of a photon is zero. The mass of a photon is by virtue of its motion.

(4) Momentum:

$$E = m c^2$$

& $$E = h \nu$$

$$mc^2 = h \nu$$

$$(mc)c = h \nu$$

$$mc = \frac{h\nu}{c}$$

$$\boxed{p = \frac{h\nu}{c}}$$

This is the expression for momentum of photon.

(5) CHARGE:

Photon is an electrically neutral particle, thus it is not affected by electric or magnetic fields.

(6) STABILITY:

It is a stable particle with infinite life time. It does not decay spontaneously into any other particle.

(7) INTERACTION:

It does not undergo interaction with other particles.

(8) ANTIPARTICLE:

Photon is the only known particle whose antiparticle does not exist. Thus, it may be regarded as a **buffer** between matter and energy.

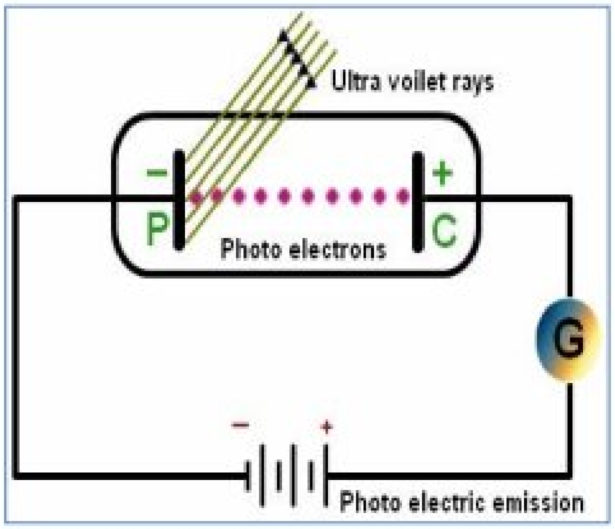
The Photoelectric effect or the Hertz effect

Introduction:

This phenomenon was first observed by **H.R. HERTZ** in **1887**.

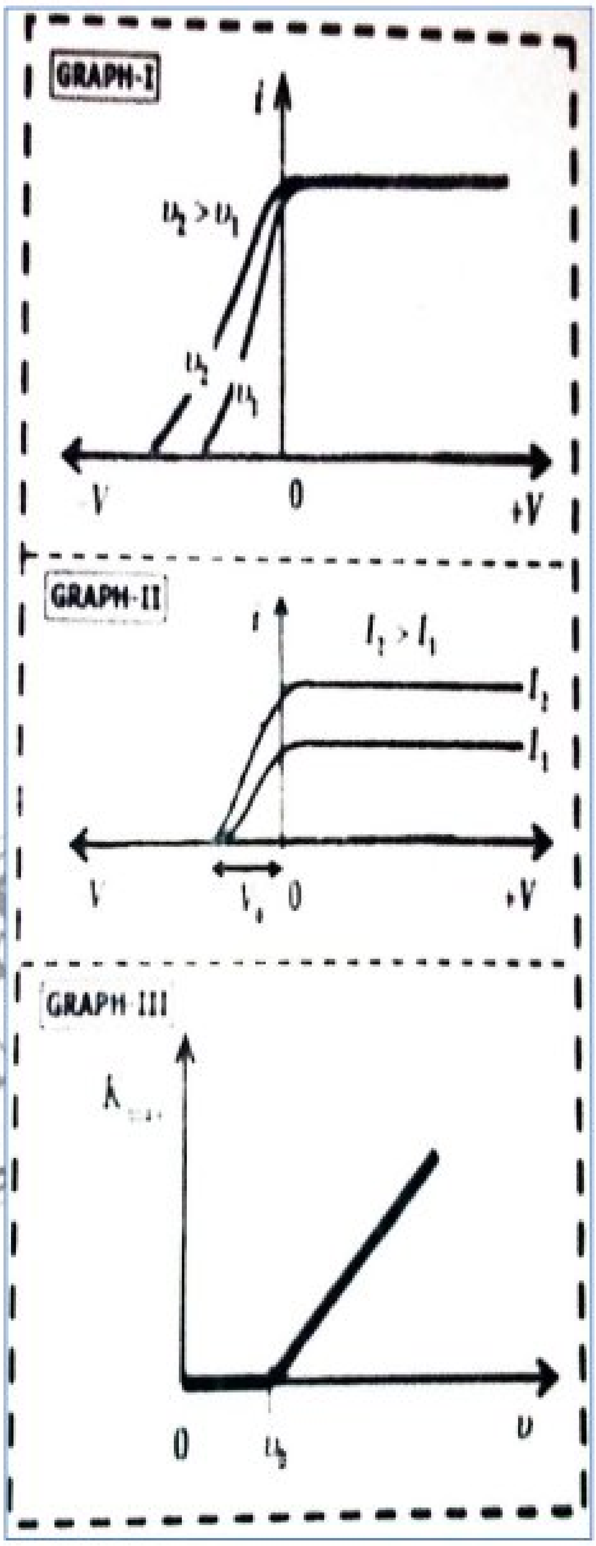
Definition:

"Emission of electrons from a metal surface when it is exposed to light of suitable frequency is called PHOTOELECTROC EFFECT. The electrons so emitted are called PHOTOELECTRONS, and the current due to these electrons is PHOTOCURRENT."



EXPERIMENTAL SET-UP:

The figure show a typical apparatus used to study the photoelectric effect, in which G is an evacuated glass tube, P is a metal plate which emits electrons called **EMITTER,** and C is the **COLLECTOR** electrode which collects electrons. When light falls on plate P the galvanometer shows a current when light is switched off the photocurrent stops.



IMPORTANT FEATURES:

(1) SATURATION CURRENT:

When positive potential of collector C is made large enough, the photoelectric current reaches a max^m constant value, at which c collects all electrons ejected from P. This current is called **SATURATION CURRENT (i_0)**

(2) STOPPING POTENTIAL:

The minimum –ve voltage on collector **c** **w.r.t P** required to stop photoelectrons is called **STOPPING POTENTIAL**(V_0). At this potential the photocurrent drops to zero.

This potential difference multiplied by electronic charge e, gives the K.E of the most energetic photoelectrons:

$$K_{max} = \frac{1}{2}mv^2 = eV_0$$

(3) THRESHOLD FREQUENCY:

The minimum frequency of incident light required to eject electrons with no. K.E from the metal surface is called **THRESHOLD FREQUENCY**(v_0). It depends upon the nature of metal surface.

(4) WORK FUNCTION:

The minimum energy required to eject an electron from metal surface, i.e. to overcome the binding force of the nucleus, is called **WORK FUCTION** (Ø). This is the energy corresponding to threshold frequency, i.e.

$$\boxed{\emptyset = hv_0}$$

EXPERIMENTAL OBSERVATIONS:

(1) The higher the frequency of incident light, the greater the K.E $\left(\frac{1}{2}mv^2 = eV_0\right)$ of photoelectrons. **(GRAPH-I)**.

(2) Increases in intensity of the source of light increases the number of photoelectrons and saturation current but does not increases K_{max}**(GRAPH-II)**.

(3) For each metal is a certain frequency v_0 below which no photoelectrons at all are emitted (GRAPH-III).

FAILURE OF CLASSICAL WAVE THEORY OF LIGHT:

Three major features could not be explained in terms of Classical Wave Theory of light.

(1) According to wave theory, the photoelectric effect should occur for any frequency of light, because electrons may come out by absorbing enough energy from incident light.

(2) The velocity and hence the K_{max} of photoelectrons should depend upon the amplitude i.e intensity of light beam, rather than frequency.

(3) For weak intensity of light, there should be a time lag between the incidence of light on the surface and ejection of photoelectrons.

EINSTEIN'S EXPLANATION ON THE BASIS OF QUANTUM THEORY:

In 1905, **Albert Einstein** proposed that light beam behaves like a stream of particles, with its energy concentrated into bundles, later called **PHOTONS**. The energy of a single photon is given by

E = h v (where v is the frequency of light)

According to Einstein a single photon carries an energy hv into the metal where it is absorbed by a single electron. Part of this energy is used in ejecting the electron from the metal surface, while the excess energy becomes the electron's K.E

$$\begin{pmatrix}\text{Photon's}\\ \text{Energy}\end{pmatrix} = \begin{pmatrix}\text{Work}\\ \text{Function}\end{pmatrix} + \begin{pmatrix}\text{K.E. of}\\ \text{electrons}\end{pmatrix}$$

$$h\,v = \phi + K_{\max}$$

$$h\,v = h\,v_0 + e\,V_0$$

$$e\,V_0 = h(v - v_0)$$

$$e\,V_0 = h\left(\frac{c}{\lambda} - \frac{c}{\lambda_0}\right)$$

$$e\,V_0 = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$$

These expressions are called Einstein's photoelectric Equations.

Here λ_0 is another constant of the metal surface called **CUT-OFF WAVELENGTH**, definition as:
"The maximum wavelength of incident light above which emission of photoelectrons will stop is called **CUT – OFF WAVELENGTH**."

THE COMPTON EFFECT

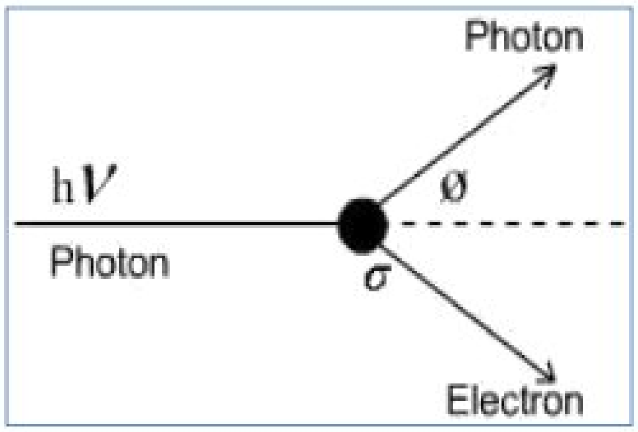
INTRODUCTION:

In 1923, Arthur H. COMPTON discovered that the wavelength of x-rays charge after they are scattered from electrons.

When a photon collides with an electron initially at rest, its frequency decreases and there is an increase in its wave length this effect is called "Compton Effect".

Dynamically:

DYNAMICAL ANALYSIS:



Let calculate the change in frequency of scattered photo by applying law of conservation of energy and Momentum.

We are considering a photon of frequency hV strikes with the electron which is initially at rest the rest mass of electron is "m_o" after striking, both are diverge in different directions as shown in Fig.

And ø are the angles of photon and electron respectively.

So we calculate the change in frequency and wave shift or increase in wave length.

METHEMTICAL EXPERSION

Energy of Particles:

Initial energy of electron	=	m_oc^2
Final energy of electron	=	mc^2
Gain in electron energy	=	$mc^2 - m_oc^2$
Initial energy of Photon	=	$h\nu$
Final energy of photon	=	$h\nu'$
Decrease in photon energy	=	$h\nu - h\nu'$

A/C to law of conservation of Energy:

Decrease in photon energy = Gain in electron energy

$$h\nu - h\nu' = mc^2 - m_oc^2 \quad \text{\_\_\_\_\_\_\_(1)}$$

Momentum of Particles:

Initial Momentum of Photon =
- X-axis = $\frac{h\nu}{c}$
- Y-axis = o

Initial Momentum of electron =
- X-axis = o
- Y-axis = o

Final Momentum of Photon
- X-axis = $\frac{h\nu'}{c}\cos\phi$
- Y-axis = $\frac{h\nu'}{c}\sin\phi$

Final Momentum of electron=
- X-axis = $mv\cos\sigma$
- Y-axis = $mv\sin\sigma$

A/C To Law of Conservation of Momentum

Along X-axis:

Initial Momentum = Final Momentum

$$\frac{h\nu}{c} + O = \frac{h\nu'}{c}\cos\phi + mv\cos\sigma \quad \text{\_\_\_(2)}$$

Along Y-axis:

Initial Momentum = Final Momentum

$$O + O = \frac{h\nu'}{c}\sin\phi + mv\sin\sigma$$

Or

$$\frac{h\nu'}{c}\sin\phi = -mv\sin\theta ------(3)$$

By solving Eq (1), (2) + (3) we get a relation between V, V' and angle ϕ.

$$\frac{1}{\nu'} - \frac{1}{\nu} = \frac{h}{m_o C^2}(1-\cos\phi) \quad \text{(A)}$$

As we know that:

$$C = \lambda \nu$$

$$\nu = \frac{c}{\lambda}$$

Putting the value in Eq (A)

$$\frac{1}{\frac{C}{\lambda^1}} - \frac{1}{\frac{C}{\lambda}} = \frac{h}{m_o C^2}(1-\cos\phi)$$

$$\frac{\lambda^1}{C} - \frac{\lambda}{C} = \frac{h}{m_o C^2}(1-\cos\phi)$$

$$\frac{\lambda^1 - \lambda}{C} = \frac{h}{m_o C^2}(1-\cos\phi)$$

$$\lambda^1 - \lambda = \frac{hc}{m_o C^2}(1-\cos\phi)$$

$$\boxed{\lambda' - \lambda = \frac{h}{m_o C}(1-\cos\phi)}$$

So Eq. X shows that $\lambda' - \lambda = \Delta\lambda$ or shift in wave length or change in wave length.

PHOTOCELL

DEFINITION:

"A device in which electric current is produced by electromagnetic radiations is called PHOTOCELL."

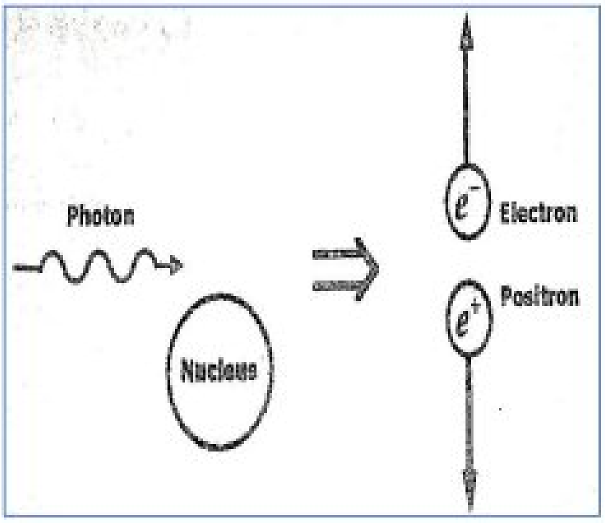
The term was originally used for photoelectric (or photo emissive) cell, but now it is commonly used for photo conducting and photovoltaic cells.

PAIR PRODUCTION

(MATERIALIZATION OF ENERGY)

DEFINITION:

"The phenomenon in which a photon passes very close to a heavy, stable nucleus and disappears producing a particle-antiparticle pair, is called PAIR PRODUCTION."



Theory:

When a photon passes in the vicinity of a heavy nucleus, it disintegrates and a pair of electron & position is created. Positron is a positively charge particle whose charge and mass are equal to the charge and mass of an electron. Factually, positron is the anti-particle of electron and is also called **ANTI-ELECTRON**.

(1) CONSERVATION OF CHARGE:

Charge of incident photon is zero after interaction, electron & position have equal and opposite charges, therefore their net charge is also zero. Hence charge is conserved

(2) CONSERVATION OFMOMENTUM:

To conserve momentum, the presence of a heavy nucleus is necessary which takes the recoil. Thus, this process does not take place in free space.

(3) CONSERVATION OFMASS-ENERGY:

The rest masses of electron and positron are equal, each being m_0 .Thus, the total rest mass energy of the pair is **$2m_0c^2$**.Hence, the minimum energy of the photon ($h\nu$) must be equal to **$2m_0c^2$ (1.02 MeV)**. The excess energy becomes the K.E of the pair.

$$h\nu = 2m_0c^2 + K_{e^-} + K_{e^+}$$

CONCLUSION:

This process shows that an energy packet transforms into massive particles, and is in conformity with mass-energy equivalence **$E=mc^2$.** Thus, it is also called **MATERIALIZATION OF ENERGY**.

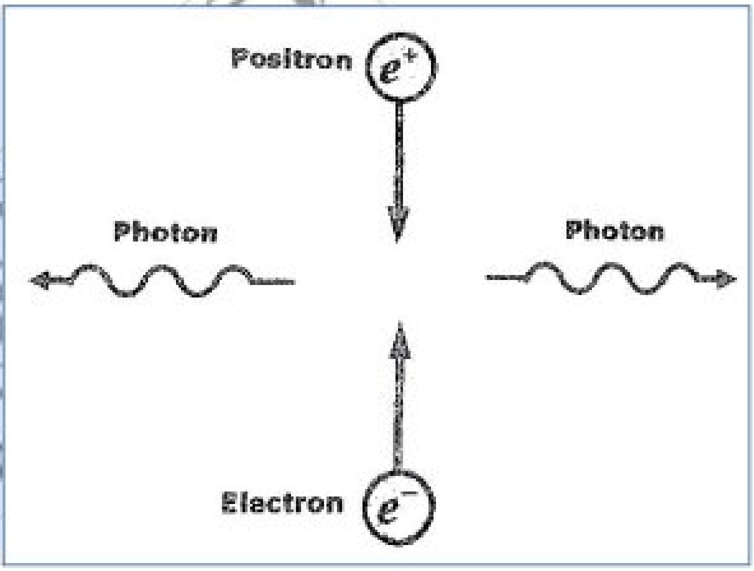
ANNIHILATION OF MATTER

INTRODUCTION:

In this process energy is created from mass, i.e. it is the reverse process of pair production.

DEFINITION:

"The conversion of a particle and its anti-particle into electromagnetic radiation of energy equal to their total rest energy) due to collision is called ANNIHILATION OF MATTER."



THEORY:

In this process, an electron combines with a positron. The two particles disappear and their mass appears as two gamma (γ) photons.

(1) CONSERVATION OF CHARGE:

Electron & positron have equal and opposite charges, therefore their net charge is zero. After interaction, the net charge of photons is also zero. Hence charge is conserved.

(2) CONSERVATION OF MOMENTUM:

To the two photons are emitted in opposite directions in order to conserve momentum.

(3) CONSERVATION OFMASS-ENERGY:

The conservation of energy for this process will be.

$$2m_0c^2 + K_{e^-} + K_{e^+} = 2h\nu$$

Eachγ-ray photon has energy $\geq$**0.51 MeV** (rest mass energy of electron/positron)

CONCLUSION:

This phenomenon proves that matter and antimatter cannot co-exist in the same frame.

WAVE NATURE OF PARTICLES &DE BROGLIE HYPOTHESIS

INTRODUCTION:

In 1924, **Louis DE BROGLIE** proposed the concept that if electromagnetic radiation has a dual wave-particle aspect, then material particles should also have a dual character.

HYPOTHESIS:

According to Einstein's Special Theory of Relativity,

$$\boxed{E = mc^2} \quad \text{---①}$$

According to Planck's Quantum Theory

$$\boxed{E = h\upsilon} \quad \text{---②}$$

Comparing eqn ① & eqn ②, we get:

$$mc^2 = h\upsilon$$

$$mc = \frac{h\upsilon}{c}$$

$$p = \frac{h\upsilon}{c}$$

$$p = \frac{h}{\lambda}$$

$$\boxed{\lambda = \frac{h}{p}}$$

$$\left[\begin{array}{l} \because\ \upsilon = \upsilon\lambda \\ \Rightarrow c = \upsilon\lambda \\ \Rightarrow \dfrac{1}{\lambda} = \dfrac{\upsilon}{c} \end{array}\right]$$

The above expression gives a connection between a wave-like property 'λ' **of radiation and a particle-like property '*P*'**

De Broglie suggested that the same relationship connects the particle-like and wave-like properties of matter. Thus, a wave is associated with a moving particle of momentum $p = m\upsilon$ whose wavelength λ is given by:

$$\boxed{\lambda = \frac{h}{m\upsilon}}$$

The wave associated with a material particle is called **DE-BROGLIE WAVE** or **MATTER WAVE**.

CONCLUSION:

The wave and particles aspects of a moving body can never be observed simultaneously. In certain situations a moving body exhibits wave properties and in other it exhibits particle properties.

PROPERTIES OF MATTER WAVES:

(1) They are pilot waves, i.e they guide the particle.
(2) The large the mass of a particle, the shorter is associated wavelength.
(3) The velocity of the matter wave is not constant.
(4) The velocity of matter wave is inversely proportional to the associated wavelength of the particle moving in vacuum.
(5) The matter wave is a wave of probability associated with a moving particle.

HEISENBERG'S UNCERTAINTY PRINCIPLE

INTRODUCTION:

In 1927, W.K.HEISENBERG proposed his famous Uncertainty principle. It sets an upper limit to exact simultaneous determination of quantities like position, momentum and energy.

STATEMENT:

"It is impossible to determine the position and momentum of a particle simultaneously with unlimited precision."

MATHEMATICAL EXPRESSION:

If Δp is uncertainty in momentum, and Δx is uncertainty in position,
Then mathematically:

$$\boxed{\Delta p \,.\, \Delta x \geq \hbar}$$

Explanation:

In order to observe an electron we use radiation of wavelength λ , consisting of photons momentum

UNCERTAINTY IN MOMENTUM:

When one photon hits an electron, some of momentum of photon is transferred to electron and it is scattered. Exact change in momentum of photon cannot be predicted but it can be said that, the max^m change in momentum can be to the order of $\frac{h}{\lambda}$, it 100% transfer of momentum is envisaged.

Thus, max^m uncertainty in the change in momentum will be:

$$\boxed{\Delta p \approx \frac{h}{\lambda}} \quad \text{---①}$$

Thus, in order to reduce uncertainty in momentum, radiation of larger λ has to be used.

UNCERTANITY IN POSITION:

When photon strikers the electron, the position of electron also charges. But change in position of electron cannot be greater than wavelengthof light used. Hence, max^m uncertainty in change in position is of the order of λ, i.e.

$$\boxed{\Delta x \approx \lambda} \quad \text{---②}$$

Thus, in order to reduce uncertainty in position of shorter λ has to be used.

Final expression:

Now Eqn① requires radiation larger λ to reduce uncertainty in momentum,

And Eqn② requires radiation shorter λ to reduce uncertainty in position.

Thus, accurate measurement of both Δp and Δx is not possible

If we try simultaneous determination of both, then multiplying eqn ① and eqn②

$$\Delta p \,.\, \Delta x \approx \frac{h}{\lambda} \,.\, \lambda$$

$$\boxed{\Delta p \,.\, \Delta x \approx h}$$

This is the mathematical from of Heisenberg's uncertainty principle.

UNCERTAINTY IN ENERGY & TIME:

If ΔE is uncertainty in energy, and Δt is uncertainty in time,

Then mathematically: $\boxed{\Delta E \,.\, \Delta t \geq \hbar}$