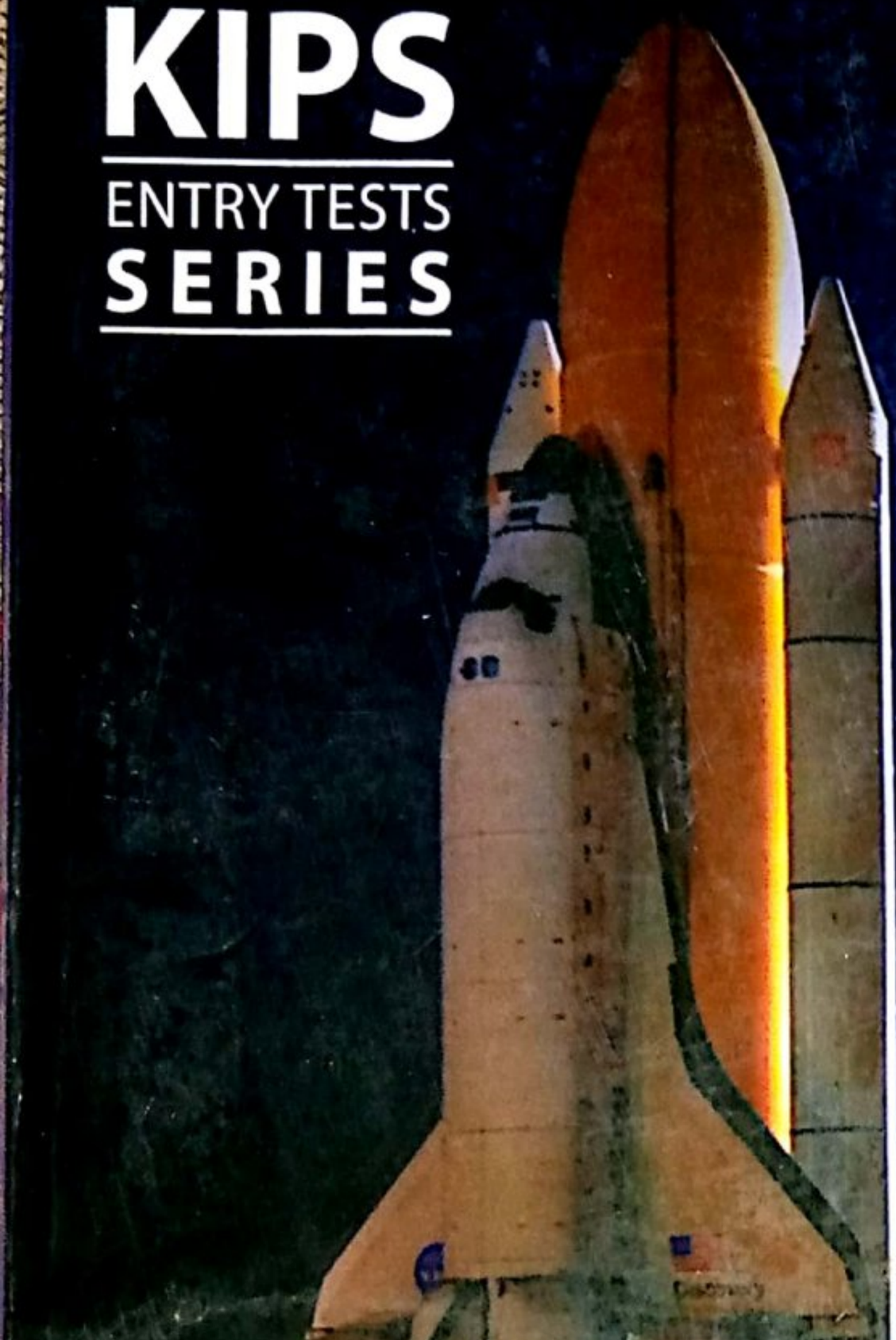
KIPS
ENTRY TESTS
SERIES

PREP BOOK



PHYSICS

FUNG

- Chapter-wise Complete Syllabus
- Comprehensive Course Revision
- Detailed Explanation of Topics
- Key Points, Tables, Flow Sheet & Diagrams
- Easy to Remember; Points to Ponder

A Kitab Dost Publication

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1 CHAPTER MEASUREMENTS

INTRODUCTION

Natural Philosophy
(A single discipline of science)

- Biological sciences (dealing with living things)
- Physical sciences (concerned with non living things)
  - Physics
    - "Physics is an experimental science that deals with the study of matter, energy and their mutual relationship".
  - Chemistry
  - Astronomy
  - And many more

Fundamental Sciences

- World of extremely large things. Such as universe.
- World of extremely small things. Such as electrons, protons
- World of complex matter or middle sized things, such as molecules, earth

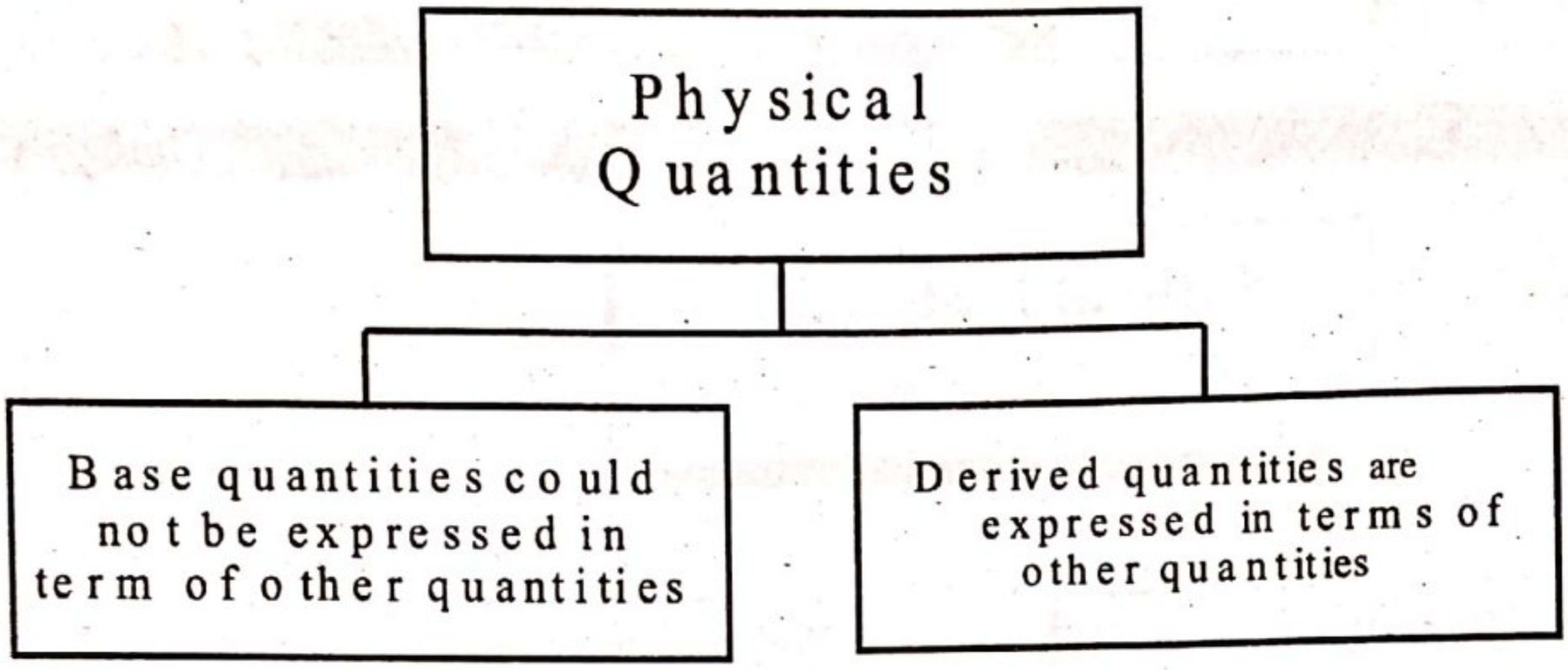
The silicon chips (processed form sand) are utilized in the development of computers and electronic devices used to control the various systems. We create networks from computers, thus interconnecting various work stations with each other.

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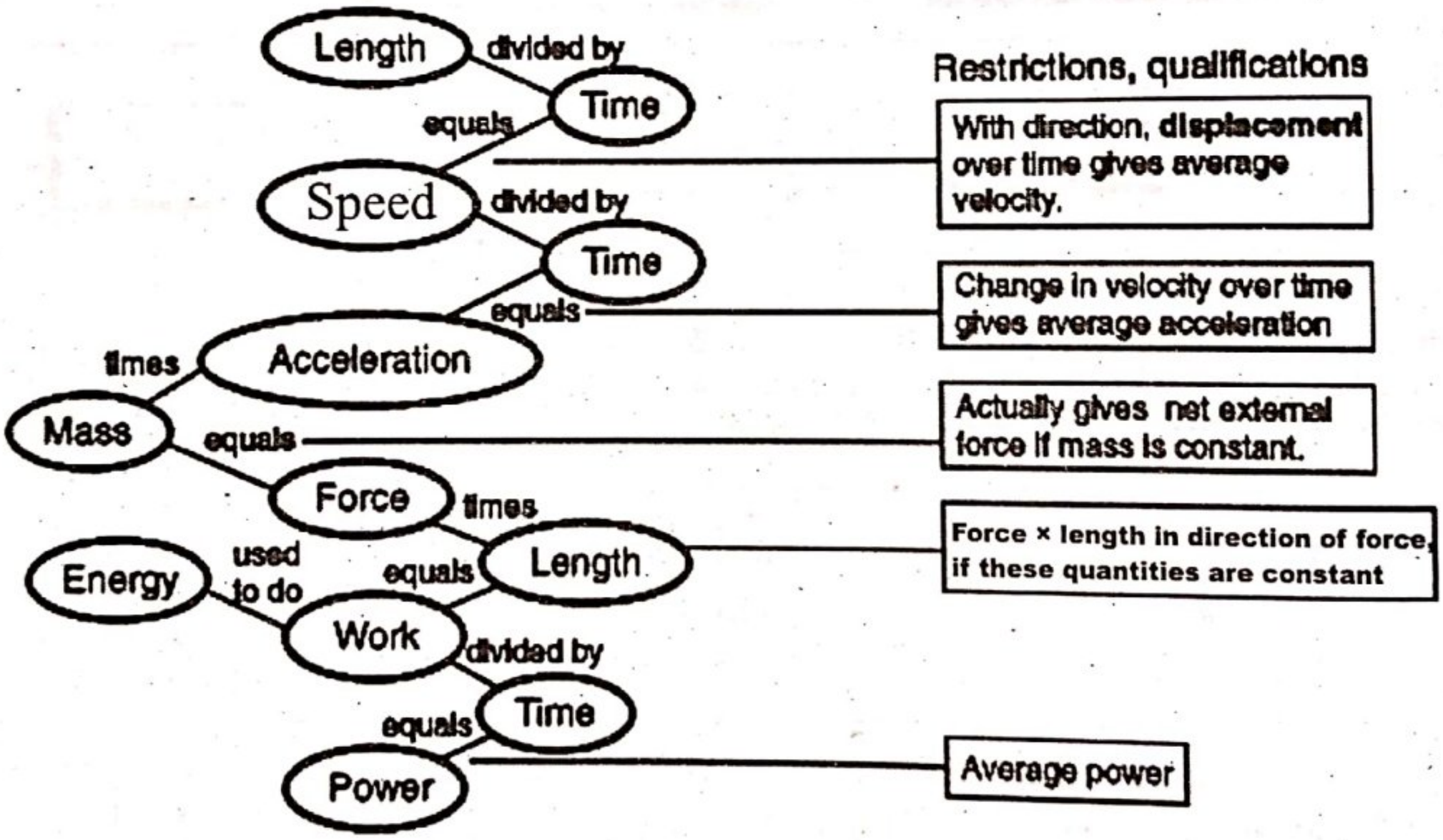
PHYSICAL QUANTITIES

Physical quantities are measurable quantities and the laws of physics are expressed in terms of them.

Classification



Chain of Mechanical Quantities



Measurements of the quantities require the following steps.

- Comparison of quantity to be measured with a standard measuring tool.
- Encoding the result of comparison in standard format containing a suitable precise number along with appropriate unit.

Measurement of basic quantities requires the choice of standard and the choice of a standard.

- Second the establishment of a procedure for comparing the quantity to be measured with the standard. Ideal standard should be accessible & invariable.

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INTERNATIONAL SYSTEM OF UNITS

Prior 1960, three measuring systems were in practice.

- CGS System (centimeter, gram, second)
  FPS System (foot, pound, second), or
  British Engineering system.
- MKS System (meter, kilogram, second)

After 1960, internationally accepted standard is SI system. In system international (SI), there are three types of units.

POINT TO PONDER

Ideal standard measuring tool should be fool proof via accessibility & invariability

Supplementary Units

Physical Quantity	SI Unit	Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

Basic Mechanical Units

	SI Units (MKS)	(CGS)	U.S. Common
Length [L]	meter (m)	centimeter (cm)	foot (ft)
Time [T]	second (s)	second (s)	second (s)
Mass [M]	kilogram (kg)	gram (gm)	slug
Velocity [L/T]	m/s	cm/s	ft/s
Acceleration [L/T^2]	m/s^2	cm/s^2	ft/s^2
Force [ML/T^2]	kg m/s^2 = newton (N)	gm cm/s^2 = dyne	slug ft/s^2 = pound (lb)
Work [ML^2/T^2]	N m = joule (J)	dyne cm = erg	lb ft = ft lb
Energy [ML^2/T^2]	joule	erg	ft lb
Power [ML^2/T^3]	J/s = watt (W)	erg/s	ft lb/s

Note: Many other derived units are also used for other derived quantities.11

SCIENTIFIC NOTATION

The standard to express the number in term of power of ten is called scientific notation.

Some standard prefixes for power of ten with their symbols are presented below:

Factor	Prefix	Symbol
10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{-1}	deci	d
10^{1}	deca	da
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E

POINT TO PONDER

There should be one non-zero digit to the left of decimal in scientific notation.

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ERRORS AND UNCERTAINITIES

The difference between standard and experimental values is called error.

Classification of Errors

- Assignable Errors (Systematic Errors)
- Un assignable Errors (Random Errors)

Assignable Errors

The errors to which we can assign a cause usually they follow same trend of variations so a cause can be assigned to them e.g. Errors occurring due to the L.C of the measuring instrument.

Remedy

Such errors can be controlled experimentally while carefully monitoring the measurement process.

Un Assignable Errors

To which we can't assign a cause because they do not follow a trend. So these errors are due to unknown causes.

Remedy

These errors can't be controlled experimentally, but a statistical tool of taking average of several values is employed to minimize them.

SIGNIFICANT FIGURES

Uncertainty in the measurements leads us to establish some standard to write the numerical value of a measurement, termed as significant figure.

"In any measurement, all the accurately known digits and the first doubtful digit are named as significant figures."

Rules of significant figures

In order to determine significant figures in a number we must follow the following rules:

(1) All the non-zero digits are significant figures.

For Example:

3.456 has four significant figures.

12.3456 has six significant figures.

(2) Zeros between non-zero digits are significant.

For Example:

2306 has four significant figures.

20, 0894 has six significant figures.

(3) Zeros locating the position of decimal in numbers of magnitude less than one are not significant.

For Example:

In the 0.2224 and 0.000034, zeros are not significant.

(4) Final zeros to the right of the decimal point are significant.

For Example:

3.0000 has four significant zeros and has five significant figures.

1002.00 has four significant zeros and has six significant figures.

(5) Zeros that locate decimal point in numbers greater than one are not significant.

For Example:

30000 has only one significant figure.

120000 has two significant figures.

POINT TO PONDER

Greater the significant figures in a measurement the more accurate it is

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However, in integers such as 8,000 kg, the number of significant zeros is determined by the accuracy of the measuring instrument. If the measuring scale has a least count of 1 kg then there are four significant figures written in scientific notation as 8.000×10^3kg. If the least count of the scale is 10kg, then the number of significant figures will be 3 written in scientific notation as 8.00×10^3 kg and so on.

Algebra with Significant Figures

(i) Division and Multiplication

(a) $$\frac{4.54\times 2.324}{1.3365} = 7.89447063 = \begin{pmatrix}\text{an answer having maximum}\\ \text{of three digits can be retained here}\end{pmatrix} = 7.89$$

(b) $$4.3458 \times 2.7 = 11.73366 = \begin{pmatrix}\text{an answer having maximum}\\ \text{of two digits can be retained here}\end{pmatrix} = 12$$

The factor having the smallest number of significant figures is called least accurate factor, and product and quotient cannot have number of significant figures more than that in the least accurate factor.

(ii) Addition and Subtraction

Search for the least number of decimal places, counting the number of significant figures is not required. For example:

(a) $$4.345+23.51=27.855=\begin{pmatrix}\text{an answer having maximum}\\ \text{of two decimal places}\end{pmatrix}=27.86$$

(b) $$101.2401-1.0=100.2401=\begin{pmatrix}\text{an answer having maximum}\\ \text{of one decimal place}\end{pmatrix}=100.2$$

(c) $$101.2401-1=100.2401=\begin{pmatrix}\text{an answer having no}\\ \text{decimal place}\end{pmatrix}=100$$

ROUNDING OFF DATA

Rule # 1:

If the digit to be dropped is greater than 5, then add "1" to the last digit to be retained and drop all digits farther to the right.

For example:

3.677 is rounded off to 3.68 if we need three significant figures in measurement.

3.677 is rounded off to 3.7 if we need two significant figures in measurement.

Rule # 2:

If the digit to be dropped is less than 5, then simply drop it without adding any number to the last digit.

For example:

6.632 is rounded off to 6.63 if we need three significant figures in measurement.

6.632 is rounded off to 6.6 if we need two significant figures in measurement.

Rule # 3:

If the digit to be dropped is exactly 5 then:

(A) If the digit to be retained is even, then just drop the "5".

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For example:

6.65 is rounded off to 6.6 if we need two significant figures in measurement.

3.4665 is rounded off to 3.466 if we need four significant figures in measurement.

(B) If the digit to be retained is odd, then add "1" to it.

For example:

6.35 is rounded off to 6.4 if we need two significant figures in measurement.

3.4675 is rounded off to 3.468 if we need four significant figures in measurement.

Remember: Zero is an even number

3.05 is rounded off to 3.0 if we need two significant figures in measurement.

PRECISION & ACCURACY

Precision

The precision of a measurement is determined by the least count of the instrument or device. Smaller the least count of instrument, more precise is the measurement. Maximum absolute uncertainty is equal to one least count of the measuring instrument.

Accuracy

The accuracy of a measurement depends upon the fractional or percentage uncertainty in the measurement.

Smaller the percentage error, more accurate is the measurement.

- Percentage uncertainty $= \frac{L.C}{\text{measured value}} \times 100$

ASSESSMENT OF TOTAL UNCERTAINTY IN THE FINAL RESULT

Total uncertainty in the final result can be determined by the following rules:

- In case of addition and subtraction absolute uncertainties are added.
- In case of multiplication and division fractional or percentage errors are added.
- For power factor the power is multiplied with the percentage uncertainty.

  For example: In the equation $u = kx^a$, a × percentage error in x, where k is constant of proportionality.

  Uncertainty in the average value of many measurements of the same quantity is the mean of absolute differences of measurements form the average value.
- For time measurement, uncertainty is obtained by dividing the least count of the timing device with the number of vibrations.
- Uncertainty in timing experiment $= \frac{\text{time}}{\text{no. of vibration}}$ with uncertainty $\frac{\text{L.C}}{\text{no. of vibration}}$

POINT TO PONDER

Counting more number of vibrations can reduce the uncertainty in the timing experiments.

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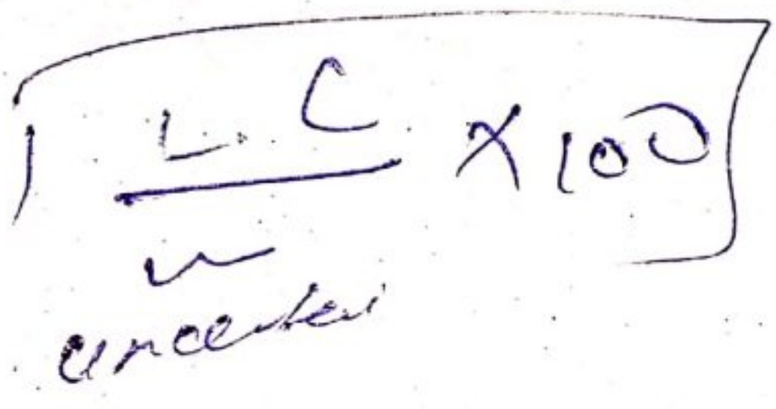
DIMENSIONS OF PHYSICAL QUANTITIES

Each basic measurable physical quantity is represented in term of base quantities by a specific symbol for them written with in square brackets is called dimension.

- The dimensions are helpful in-
  - ✦ Deriving a possible formula
  - ✦ Checking the homogeneity of a physical equation or formula.

Limitations of Dimensional Analysis

- Dimension analysis has no information of proportionality constants.
- If a quantity is dependent on trigonometric or exponential function, this method cannot be used.
- In some cases, it is difficult to guess the factors while deriving the relation connecting two or more physical quantities.
- This method cannot be used in an equation containing two or more variables with same dimensions.



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2 CHAPTER

VECTORS AND EQUILIBRIUM

INTRODUCTION

Physical Quantities
(A property of the matter associated with measurement)

- **Scalar quantity** (having magnitude but no direction)
- **Vector quantity** (having magnitude as well as direction)

BASIC CONCEPTS OF VECTORS & SCALARS

Comparison of Scalar and Vector

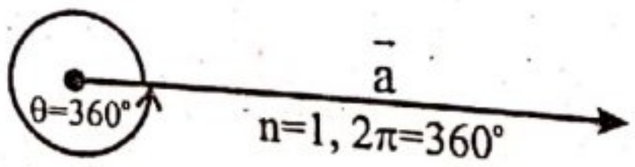
PARTICULARS	SCALARS	VECTORS
Definition	Non-directional physical quantity	Directional physical quantity
Examples	time, volume, work & flux	Displacement, velocity & torque
Representation requirements	Numerical value Proper unit	Numerical value Proper unit Direction
Subtraction	By simple arithmetic rules	By special rules
Addition	By simple arithmetic rules	By special rules
Multiplication	By simple arithmetic rules	By special rules
Division	By simple arithmetic rules	Not possible

Modulus of a Vector

It represents only the magnitude of a vector, i.e., absolute numerical value of the vector. It gives no information about direction of the vector.

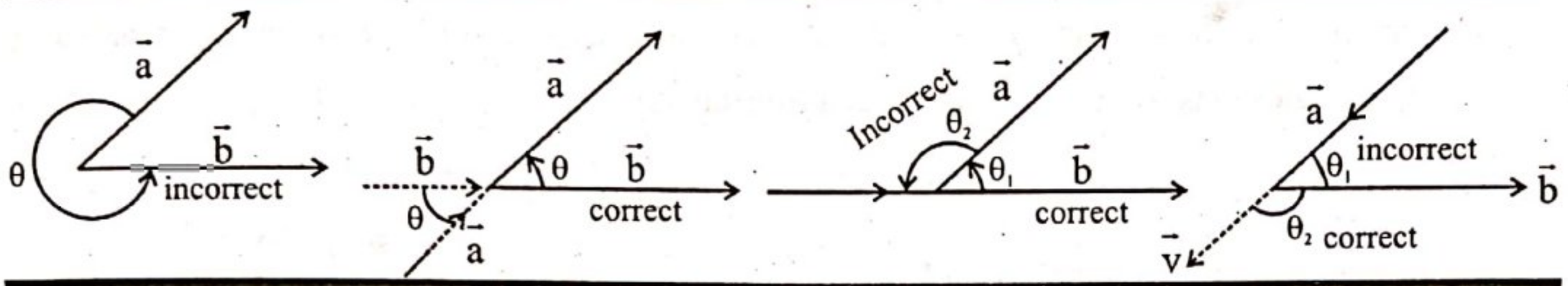
If $\vec{a} = (5N)(East)$, $\vec{b} = (5N)(West)$ then $\vec{a} \neq \vec{b}$ but $|\vec{a}| = |\vec{b}| = 5N$

- **A vector does not change: (i)** When a vector is displaced parallel to itself anywhere in space. **(ii)** When a vector is rotated through an angle θ keeping its tail fixed such that $\theta = 2n\pi$ where $n = 1, 2, 3, \ldots\ldots$

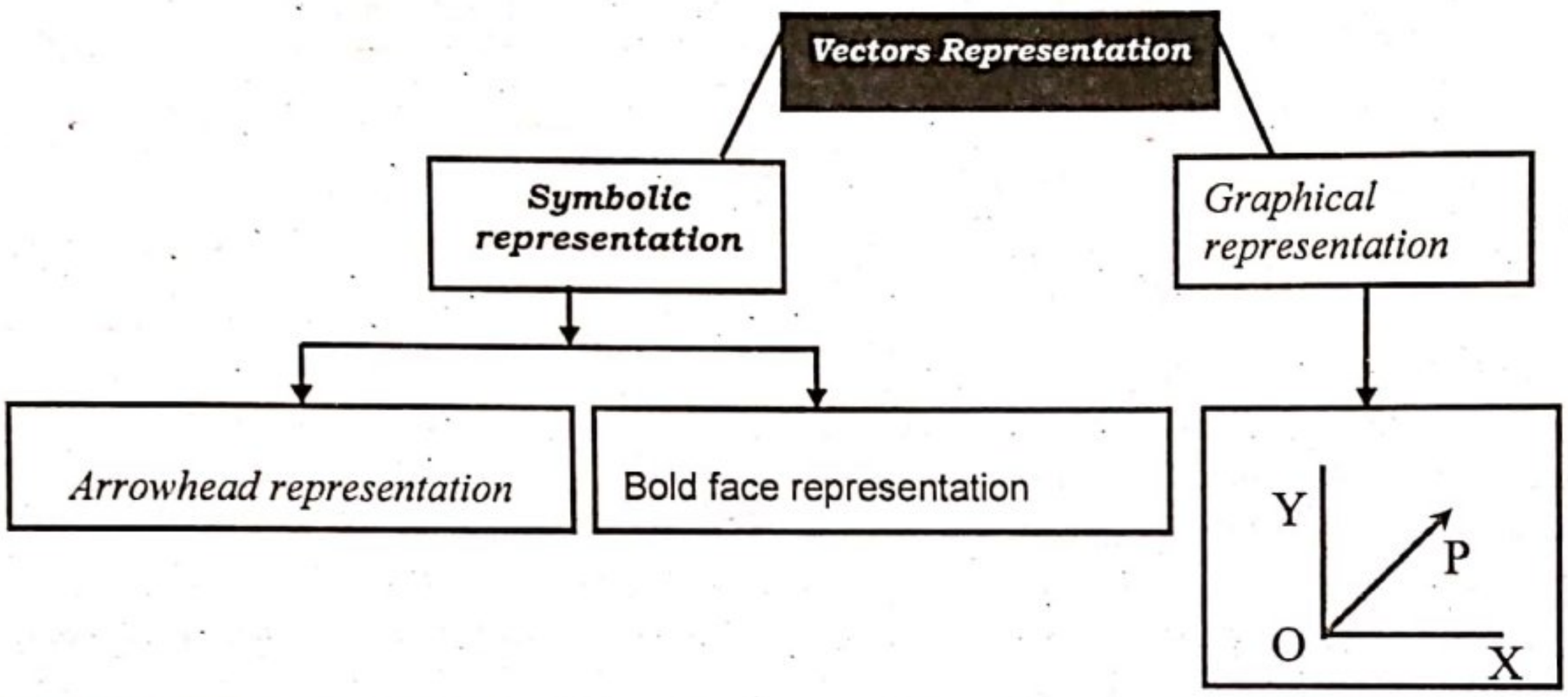


- **A vector changes when: (i)** Its magnitude changes only. **(ii)** Its direction changes only, i.e., angle of rotation of a vector is not an integral multiple of 2π. **(iii)** Both magnitude and direction change.
- **Angle between two vectors:** It is measured only when their tails or heads are at the same point.

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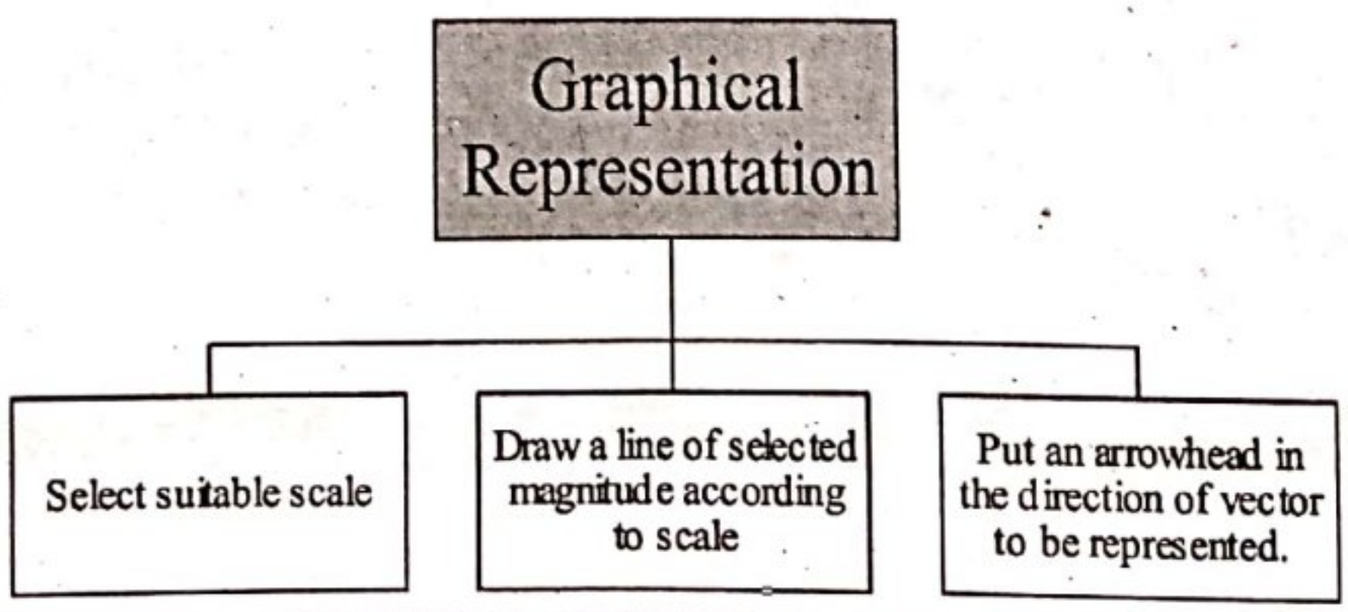
VECTOR REPRESENTATION



POINT TO PONDER

Angular representation of vectors involves measurement of angle with positive x-axis in anticlockwise sense.

Steps to Represent Vectors Graphically



RECTANGULAR COORDINATE SYSTEM

Two-dimensional

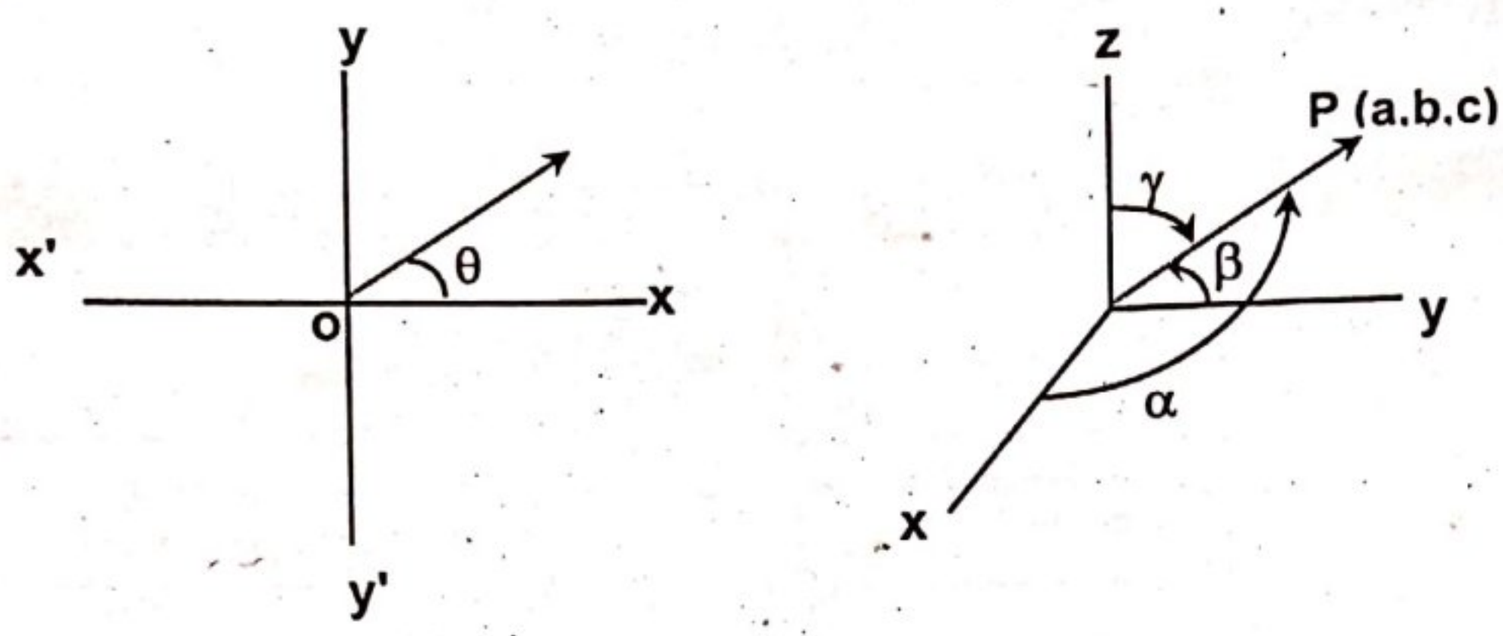
It consists of two mutually perpendicular intersecting lines, called x-axis and y-axis. One angle is enough to specify the direction of a vector in two-dimensional coordinate system.

Three-Dimensional

It consists of three mutually perpendicular lines called x-axis, y-axis and z-axis.

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The direction of a vector in three dimensional rectangular coordinate system is specified by three angles making with x, y and z-axis respectively.



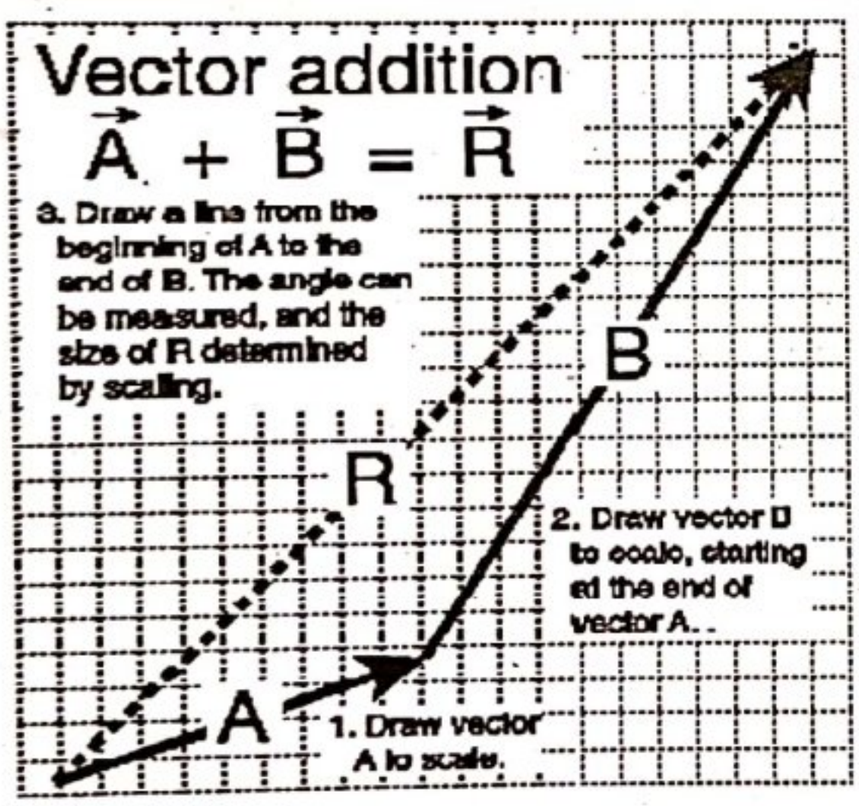
Origin

It is the point of intersection of mutually perpendicular lines in rectangular coordinate system.

Addition and Subtraction Of Vectors

- We can add and subtract vectors by head to tail rule that states:
  "If vectors are arranged in such a way that tail of each next vector join with the head of its preceding vector, then the resultant is obtained by a line joining the tail of first vector to the head of last one."

GRAPHICAL VECTOR ADDITION



Adding two vectors **A** and **B** graphically can be visualized like two successive walks, with the vector sum being the vector distance from the beginning to the end point. Representing the vectors by arrows drawn to scale, the beginning of vector B is placed at the end of vector A. The vector sum R can be drawn as the vector from the beginning to the end point.

The process can be done mathematically by finding the components of A and B, combining to form the components of R, and then converting to polar form. (R,θ)

TYPES OF VECTORS

Resultant Vector

It is a single vector that has the same effect as all the vectors to be added.

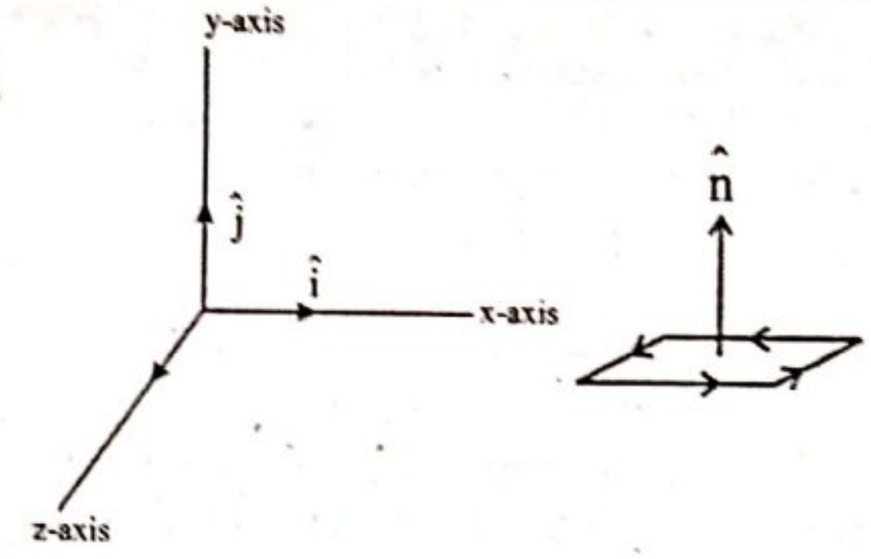
Unit Vector

It has magnitude **1** and direction of it is along the given vector. It is obtained by dividing the vector with its magnitude i.e. $\hat{A}=\frac{\vec{A}}{|\vec{A}|}$.

- "A unit vector has no dimensions and it is unitless."
  Some commonly used unit vectors are

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$\hat{i}$ - unit vector along x-axis
$\hat{j}$ - unit vector along y-axis
$\hat{k}$ - unit vector along z-axis
$\hat{r}$ - unit vector along position vector
$\hat{n}$ - unit vector along normal (perpendicular)



Zero Vector or Null Vector

It has magnitude zero and arbitrary direction. Its symbol is **O** and used as vector identity for addition. $\vec{A}+\left(-\vec{A}\right)=\vec{0}$

Negative of a vector

It is a vector of same magnitude but has opposite direction e.g.

$\xrightarrow{\vec{A}}$

$\xleftarrow{-\vec{A}}$

POINT TO PONDER

We cannot add zero to null vector.

Equal Vectors

Vectors having same magnitude and same direction are said to be equal vectors.

Parallel Vectors

The vectors that have only same direction are called parallel vectors

Anti parallel Vectors

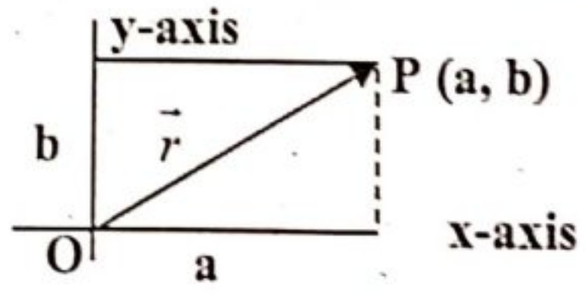
The vectors that have opposite direction are called anti parallel vectors.

Position Vector

It represents the position of a point with respect to an origin in a coordinate system. Its symbol is $\vec{r}$.

In two dimensions, $\vec{r} = a\hat{i} + b\hat{j}$

In three dimensions, $\vec{r} = a\hat{i} + b\hat{j} + c\hat{k}$



Multiplication of a Vector with a Scalar (Number)

- Resultant remains a vector
- Magnitude may or may not be changed as number can be 1 or >1.
- Direction may or may not be changed, as number can be positive or negative.
- e.g. if number = n & vector = $\vec{A}$, then after multiplication

  New vector $= n\vec{A}$

  Magnitude = n times the magnitude of $\vec{A}$ i.e. $n\left|\vec{A}\right|$

Dimensions of scalar and vector are also multiplied to give the dimension of new vector.

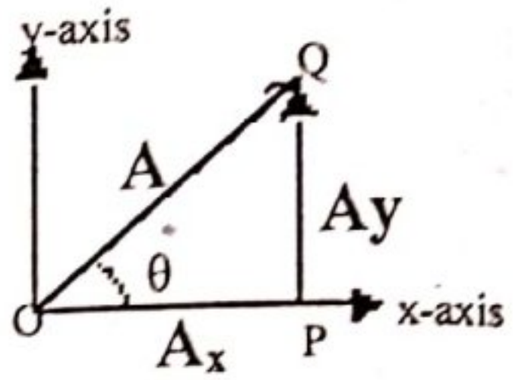
Resolution of a Vector

- Reverse process of addition of vectors.
- Replacing single vector by two or more than two vectors.
- Vectors obtained by resolving a vector are called components.
- Component of a vector is its effective value in the stated direction.
- Minimum possible components of a vector are two.
- Maximum possible components of a vector are infinite.

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RECTANGULAR COMPONENTS OF A VECTOR

- Components of vector which are mutually perpendicular.
- To apply simple trigonometric formulae we resolve vector in a plane into two mutually perpendicular components called rectangular components e.g.



Where

$A_x = A\cos\theta$---------- (i)

$A_y = A\sin\theta$----------(ii)

- Direction of components is governed by angle 'θ'.

Determination of a Vector from Rectangular Components

Squaring and adding (i) and (ii), their simplification yields.

$|\vec{A}| = \sqrt{A_x^2 + A_y^2}$ $(\cos^2\theta+\sin^2\theta=1)$

For direction dividing (i) and (ii)

$$\theta = tan^{-1}\left(\frac{A_y}{A_x}\right)$$

When vector A makes angle θ with y-axis

$A_x = A\sin\theta$

$A_y = A\cos\theta$

$$\theta = \tan^{-1}\left(\frac{A_x}{A_y}\right)$$

ADDITION OF VECTORS BY RECTANGULAR COMPONENTS

- Let resultant of two vectors **A** and **B** be **R**. Its magnitude is given as

$$R = \sqrt{(R_x)^2 + (R_y)^2}$$

Where

$R_x = A_x + B_x$

$R_y = A_y + B_y$

- Direction of the resultant vector is determined by

$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right)$$

- For any number of vectors, the magnitude of the resultant

$$R = \sqrt{(A_x + B_x + C_x + \ldots\ldots)^2 + (A_y + B_y + C_y + \ldots\ldots)^2}$$

$$\theta = \tan^{-1}\left(\frac{A_y + B_y + C_y + \ldots..}{A_x + B_x + C_x + \ldots..}\right)$$

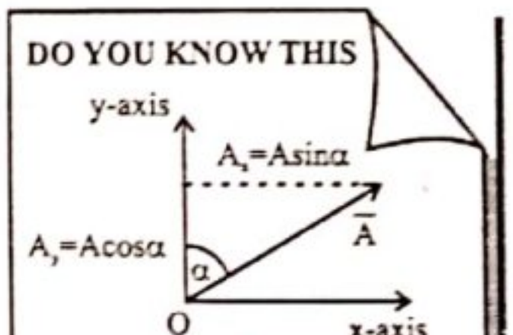
Here θ is the angle which resultant vector makes with positive x-axis

- Remember following diagram

Keeping in mind the conventions for measuring angle of resultant vector, you can calculate the angle using the table below:

S (sine positive)	A (positive)
T (tan positive)	C (cos positive)

DO YOU KNOW THIS



$\bar{A} = A_x\hat{i} + A_y\hat{j}$

$\frac{\bar{A}}{A} = \frac{A_x}{A}\hat{i} + \frac{A_y}{A}\hat{j}$

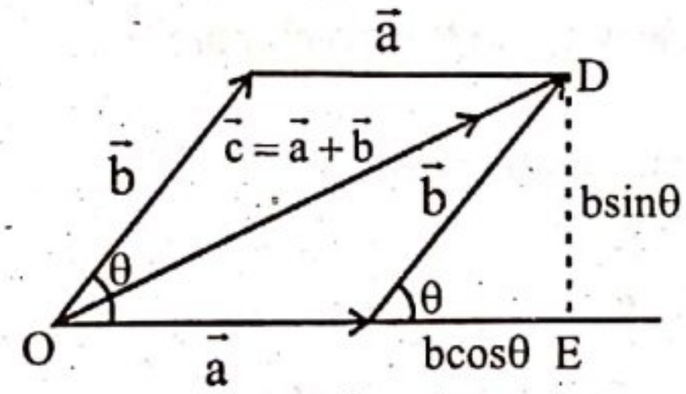
$\hat{A} = \sin\alpha\hat{i} + \cos\alpha\hat{j}$

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Situation	Quadrant	Angle calculated	Angle calculated according to conventions.
$R_x \rightarrow$ Positive $R_y \rightarrow$ Positive	1st	$\phi = \tan^{-1}\left\|\frac{R_y}{R_x}\right\|$	$\theta = \phi$
$R_x \rightarrow$ Negative $R_y \rightarrow$ Positive	2nd	$\phi = \tan^{-1}\left\|\frac{R_y}{R_x}\right\|$	$\theta = 180° - \phi$
$R_x \rightarrow$ Negative $R_y \rightarrow$ Negative	3rd	$\phi = \tan^{-1}\left\|\frac{R_y}{R_x}\right\|$	$\theta = 180° + \phi$
$R_x \rightarrow$ Positive $R_y \rightarrow$ Negative	4th	$\phi = \tan^{-1}\left\|\frac{R_y}{R_x}\right\|$	$\theta = -\phi$ or $\theta = 360° - \phi$

PARALLELOGRAM LAW

- This law is applicable only when tails of two vectors are at same point.
- In case of parallelogram law from two co-initial vectors we should make a parallelogram whose diagonal represents the resultant of these two vectors.



- Using Pythagoras theorem in right angled triangle DOE: We get:

$$c^2 = (a + b\cos\theta)^2 + (b\sin\theta)^2$$

$$c^2 = a^2 + b^2\cos^2\theta + 2ab\cos\theta + b^2\sin^2\theta = a^2 + b^2(\cos^2\theta + \sin^2\theta) + 2ab\cos\theta \quad \therefore \cos^2\theta + \sin^2\theta = 1$$

$$c^2 = a^2 + b^2 + 2ab\cos\theta \quad \text{OR} \quad c = \sqrt{a^2 + b^2 + 2ab\cos\theta}$$

- $\left|\vec{c}\right| = \sqrt{a^2 + b^2 + 2ab\cos\theta}$

If a (magnitude of $\vec{a}$) and b (magnitude of $\vec{b}$) are constant and θ varies then c will also vary because cos θ varies.

c will be maximum when cos θ = +1 i.e. θ = 0°.

Thus $c_{max} = \sqrt{(a+b)^2}$ or $c_{max} = \left|\vec{a} + \vec{b}\right|$

c will be minimum when cos θ = –1 i.e., θ = 180°. Thus,

$$c_{min} = \sqrt{(a-b)^2} \quad \text{or} \quad c_{min} = \left|\vec{a} - \vec{b}\right|$$

Hence, resultant of two vectors $\vec{a}$ and $\vec{b}$ can vary between c_{max} and c_{min}

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- **For subtraction**

$$\left|\vec{c}\right| = \sqrt{a^2 + b^2 - 2ab\cos\theta}$$

Here θ is the angle between $\vec{a}$ and $\vec{b}$.

SCALAR OR DOT PRODUCTS

If product of two vectors is a scalar, then it is called scalar product or dot product.

$\vec{A}.\vec{B} = AB\cos\theta.$

Example of dot product

Work (scalar quantity) is dot product of force and displacement vector.

POINT TO PONDER

Impulse is an example of dot product or cross product?

Characteristics of Scalar Product

Let us consider two vectors $\vec{A}$ and $\vec{B}$ to elaborate characteristics.

Scalar product holds commutative law i.e.

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

- It holds associative law i.e.

$\vec{A}.(\vec{B}.\vec{C}) = (\vec{A}.\vec{B}).\vec{C}$

- It holds distributive law i.e.

$\vec{A}.(\vec{B}+\vec{C}) = \vec{A}.\vec{B} + \vec{A}.\vec{C}$

- If $\theta = 90°$, then $\vec{A}.\vec{B} = 0$
- If $\theta = 0°$, then $\vec{A}.\vec{B} = AB$
- If $\theta = 180°$, then $\vec{A}.\vec{B} = -AB$
- For unit vectors $\hat{i}, \hat{j}, \hat{k}$

$\hat{i}.\hat{j} = \hat{j}.\hat{k} = \hat{k}.\hat{i} = 0$ *and* $\hat{i}.\hat{i} = \hat{j}.\hat{j} = \hat{k}.\hat{k} = 1$

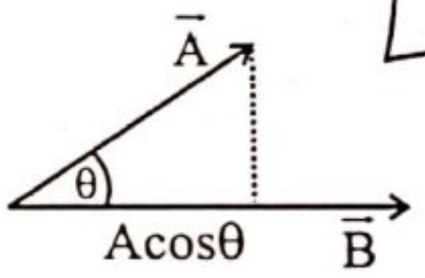
- To find angle between two vector to be multiplied.

$$\theta = \cos^{-1}\left(\frac{A_xB_x + A_yB_y + A_zB_z}{AB}\right)$$

- The result of product of two equal vectors is equal to the square of their magnitude. (Self scalar product).

$\vec{A}.\vec{A} = A^2.$

DO YOU KNOW THIS



Component of $\vec{A}$ along $\vec{B}$ is

$A\cos\theta = \vec{A}.\hat{B}$

POINT TO PONDER

Scalar product of two parallel vectors is equal to the product of their magnitudes only.

VECTOR OR CROSS PRODUCT

If product of two vectors is a vector, then it is called vector product

$\vec{A} \times \vec{B} = AB\sin\theta\ \hat{n}$

where $\hat{n}$ is normal to the plane containing vectors $\vec{A}$ and $\vec{B}$.

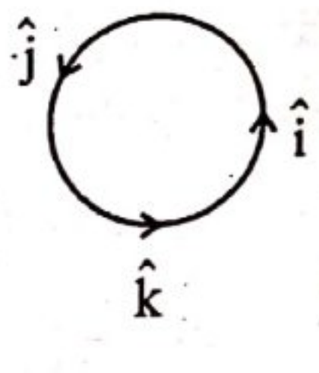
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Characteristics of vector product

- Cross product does not obeys commutative law
- $\vec{A}\times\vec{B}\neq\vec{B}\times\vec{A}$
- $\vec{A}\times\vec{A}=\vec{0}$, therefore, $\hat{i}\times\hat{i}=\hat{j}\times\hat{j}=\hat{k}\times\hat{k}=\vec{0}$
- $\vec{A}\times\vec{B}=AB\ \hat{n}$ if $\theta=90°$, therefore, $\hat{i}\ x\ \hat{j}=\hat{k}$, $\hat{j}\ x\ \hat{k}=\hat{i}$,, $\hat{k}\ x\ \hat{i}=\hat{j}$
- $m\left(\vec{A}\,x\,\vec{B}\right)=\left(m\vec{A}\right)x\,\vec{B}=\vec{A}\,x\left(m\vec{B}\right)$
- $\vec{A}\times\vec{B}=\vec{0}$ if $\vec{A}$ and $\vec{B}$ are parallel or anti-parallel vectors.
- If the direction of any vector is reversed cross product becomes negative.
- If both vectors are reversed no change in cross product occurs.
- $\vec{A}\,x\,\vec{B}=(A_yB_z-B_yA_z)\hat{i}+(A_zB_x-B_zA_x)\hat{j}+(A_xB_y-B_xA_y)\hat{k}$

OR

- $\vec{A}\times\vec{B}=\begin{vmatrix}\hat{i}&\hat{j}&\hat{k}\\A_x&A_y&A_z\\B_x&B_y&B_z\end{vmatrix}$



POINT TO PONDER

The magnitude of vector product of two vectors gives the area of parallelogram.

- The magnitude of $\vec{A}\times\vec{B}$ is equal to the area of the parallelogram formed with $\vec{A}$ and $\vec{B}$ as two adjacent sides
- Scalar triple product gives volume of parallelepiped.

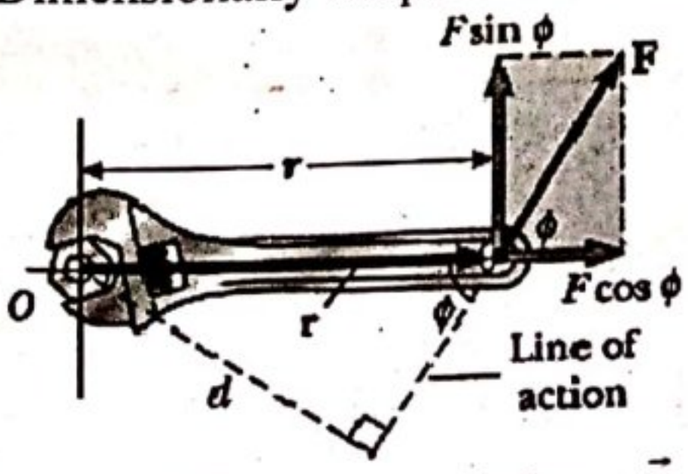
$$\vec{A}\,.\left(\vec{B}\,x\,\vec{C}\right)=A_x(B_yC_z-C_yB_z)-A_y(B_xC_z-C_xB_z)+A_z\,(B_xC_y-C_xB_y)$$

OR

- $\vec{A}\,.\left(\vec{B}\,x\,\vec{C}\right)=\begin{vmatrix}A_x&A_y&A_z\\B_x&B_y&B_z\\C_x&C_y&C_z\end{vmatrix}$

TORQUE

- A physical quantity, which produces angular acceleration, is called torque.
- Dimensionally torque resembles with work.



POINT TO PONDER

An inclined door automatically closes due to the torque produced by horizontal component of its weight.

- Torque is a vector quantity. $\vec{\tau}=\vec{r}\times\vec{F}=r\,F\sin\phi\ \hat{n}$
- Magnitude of torque is given as;

$\tau=r\,F\sin\phi\ s$

$\tau=r\,F$ if $\phi=90°$

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- SI unit of torque is N m.
- Torque is rotational analogue of force.
- Following factors affect torque:

(i) Magnitude of force

(ii) Magnitude of position vector or distance between the line of action of force and pivot point

(iii) Value of angle θ between $\vec{F}$ and $\vec{r}$.

- If line of action of force $\vec{F}$ passes through axis of rotation, then no torque is produced.
- $\tau = r F \sin\theta$

OR $\tau = (r \sin\theta) F.$

$\tau = r_\perp F$

Where $r_\perp$ is component of position vector perpendicular to force and

$r_\perp = r \sin\theta$ is called moment arm of torque.

OR

$\tau = r (F \sin\theta)$

$\tau = r F_\perp$

which shows that only perpendicular component of force contributes to torque and horizontal component does nothing in case of torque.

- If $\theta = 0°$ or π then $r_\perp = 0$ m and $F_\perp = 0$N so that $\tau = 0$ Nm.

Direction alterations

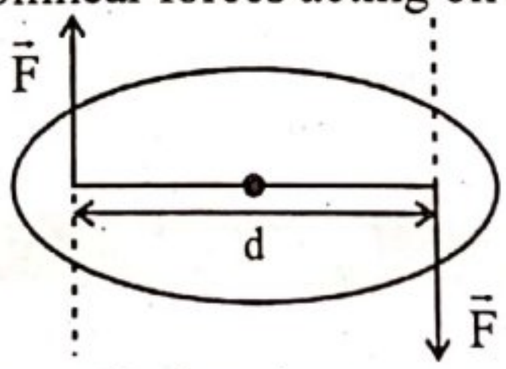
(a) If $\vec{F}$ is reversed, then direction of torque is also reversed.

(b) If $\vec{r}$ is reversed, then direction of torque is also reversed.

(c) If both $\vec{r}$ and $\vec{F}$ are reversed then the direction of torque remains unchanged.

COUPLE

Two equal, opposite and non-collinear forces acting on a body constitute a couple.

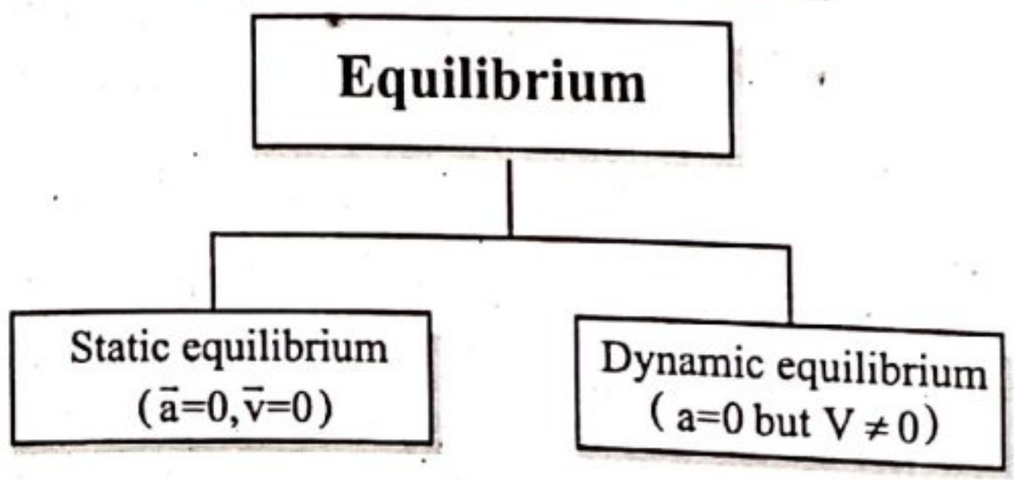


- Torque of a couple is never zero and $\tau = Fd$ where d = moment arm of couple.

EQUILIBRIUM

If a body keeps its state of rest or uniform motion invariant under many forces, it is said to be in perfect equilibrium.

KINDS OF EQUILIBRIUM



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CONDITIONS OF EQUILIBRIUM

The conditions of equilibrium can be stated in terms of coplanar forces as follow:

1st Condition of Equilibrium

The sum of forces acting on a body is equal to zero.

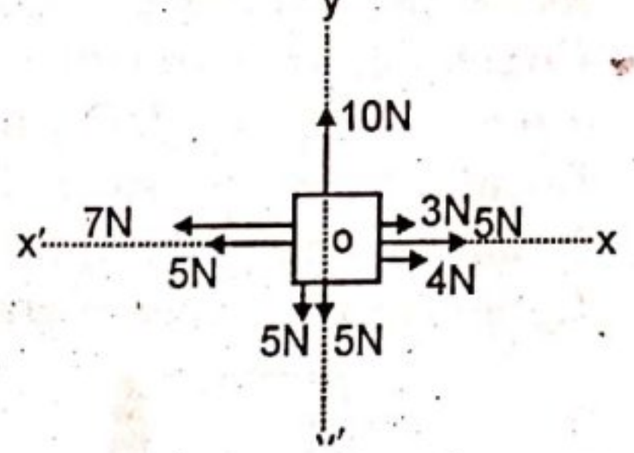
i.e. $\Sigma\vec{F} = \vec{0}$

For coplanar forces

$$\Sigma\vec{F}_x = \vec{0} \text{ and } \Sigma\vec{F}_y = \vec{0}$$

- 1st condition of equilibrium controls the translational equilibrium of the body.

Explanation: Consider a body under the action of the external forces as shown in the diagram.



Take forces along positive x-axis as positive and along negative x-axis as negative.

Sum (resultant) of forces along x-axis = ΣF_x

$\Sigma F_x = 5N + 3N + 4N - 7N - 5N = \text{zero}$

Similarly, for Y-axis,

$\Sigma F_y = 10N - 5N - 5N = \text{zero}$

Sum of all the external forces on the body i.e ΣF is zero, hence the body is in the first condition of equilibrium (Σ = Sigma = Sum)

2nd Condition of Equilibrium

The sum of torques acting on a body about the same axes of rotation is equal to zero.

Mathematically $\Sigma\vec{\tau} = \vec{0}$

Or

Sum of anticlockwise torques = Sum of clockwise torques

- 2nd condition of equilibrium controls the rotational equilibrium of the body.

Explanation: consider a body with axis of rotation O under the action of external torques as shown in the Fig. The clockwise torque is taken –ve and anticlockwise torque is taken +ve.

Clockwise torque = $-10N \times 2m$

= $-20\ N\ m$

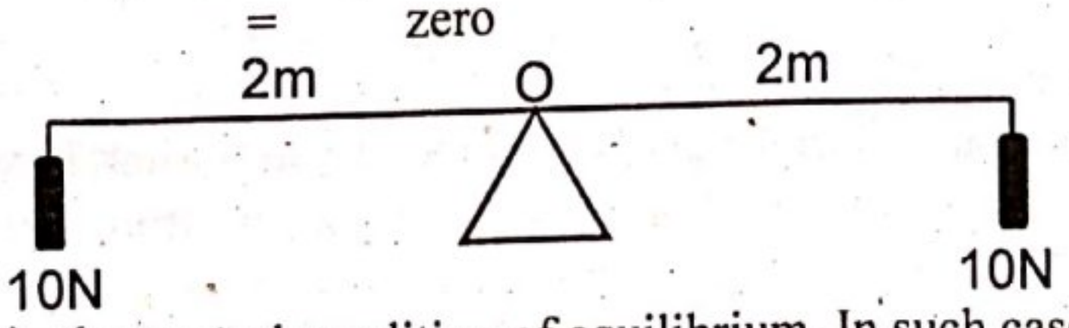
Anticlockwise torque = $10N \times 2m$

= $20N\ m$

Sum of all external torques = $\Sigma\tau$

$\Sigma\tau$ = $20\ N\ m - (20\ N\ m)$

= zero



Hence the body is in the second condition of equilibrium. In such cases:

Sum of clockwise torques = Sum of anticlockwise torques

POINT TO PONDER

Both conditions of equilibrium must be fulfilled for a body to be in complete equilibrium.

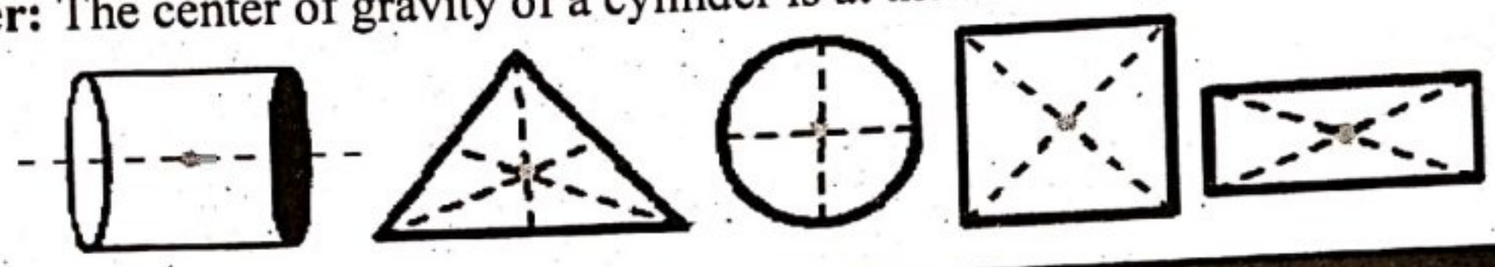
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Center of gravity

Center of gravity of a body is a point where total weight of the body is concentrated. Everybody possess a center of gravity and this is irrespective of shape of the body. It is not necessary that the center of gravity should be within the body, it may also be situated in space, outside the body. Example: center of gravity of a ring is at the center, which is in the space.

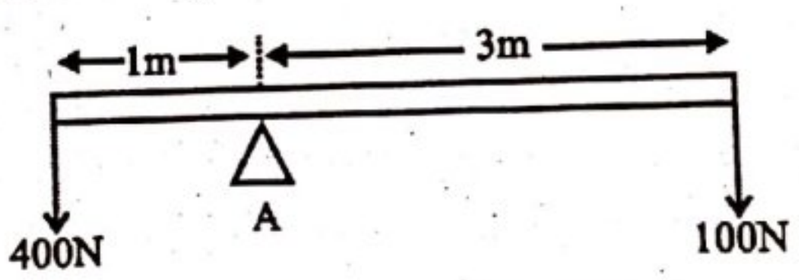
Center of gravity of different objects:

- **Rectangle:** Center of gravity of a rectangle is at the point of intersection of its diagonals
- **Circle:** Center of gravity of a circle is at its center.
- **Square:** Center of gravity of square is at the point of intersection of its diagonals.
- **Regular Bar:** The center of gravity of a regular bar is at its geometrical center.
- **Triangle:** The center of gravity of a triangle is at the point of intersection of its medians.
- **Cylinder:** The center of gravity of a cylinder is at the axis of cylinder.



CHOOSE THE CORRECT OPTION

A uniform rod loaded(as shown in the fig. below)is pivoted at the point A so that it is in equilibrium. The weight of the rod will be



(a) 700N (b) 300N (c) 500N (d) 100N

States of Equilibrium

There are three states of equilibrium:

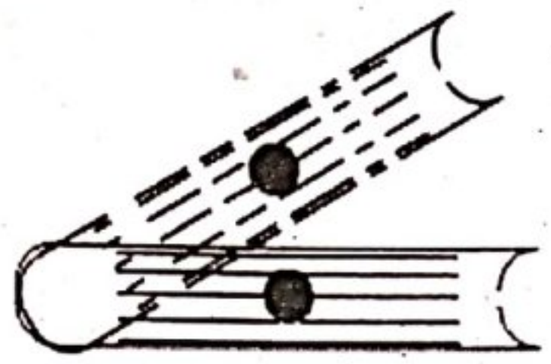
- Stable equilibrium
- Unstable equilibrium
- Neutral equilibrium

Stable Equilibrium: The stable equilibrium is the state of equilibrium in which the body comes back to its original condition when set free after slightly lifting from one side. On lifting, the centre of gravity of the body is raised up as compared to the initial position.

Explanation: A book lying on a horizontal surface is an example of stable equilibrium. If the book is lifted from one edge and then allowed to fall, it will come back to its original position. Other examples of stable equilibrium are bodies lying on the floor such as chair, table etc.

Reason of Stability: When the book is lifted its center of gravity is raised up. The line of action of weight passes through the base of the book. A torque due to weight of the book brings it back to the original position.

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Unstable Equilibrium: The unstable equilibrium is that condition of a body in which, if the position of the body is disturbed, it does not come back to its original position. In such a case, the centre of gravity is lowered than its original position.

Example: Pencil standing on its point or a stick in vertically standing position.

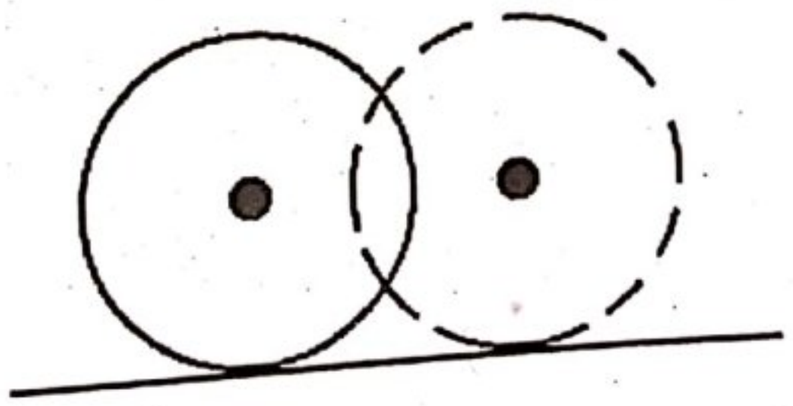
Explanation: If thin rod standing vertically is slightly disturbed from its position it will not come back to its original position. This type of equilibrium is called unstable equilibrium, other example of unstable equilibrium are vertically standing cylinder and funnel etc.

Reason of Instability: When the rod is slightly disturbed its center of gravity is lowered. The line of action of its weight lies outside the base of rod. The torque due to weight of the rod toppled it down.



Neutral Equilibrium: The type of equilibrium in which after disturbance, the body again comes to rest position and the position of its centre of gravity does not change, is called neutral equilibrium.

Explanation: If the rest position of the ball is disturbed, the ball comes to rest after moving through a small distance. The centre of gravity G of the ball is again at the centre of the ball. i.e., the position of G neither rises nor becomes lower due to motion. In this condition the centre of gravity remains at the same place.



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3 CHAPTER MOTION AND FORCE

INTRODUCTION

The concept of state of motion and rest are described relative to the observer.

- If a body does not change its position w.r.t surroundings, it is in the state of rest.
- If a body changes its position w.r.t surroundings, then it is in the state of motion.

POINT TO PONDER

A moving body can possess both states of rest and motion, depending on the observer.

DISPLACEMENT

Displacement is a vector that describes the change in the position of body from initial to final position.

Distance

The length of the path between two points is called distance.

POINT TO PONDER

When a body moves along straight line then the displacement coincides with the distance traveled.

SPEED & VELOCITY

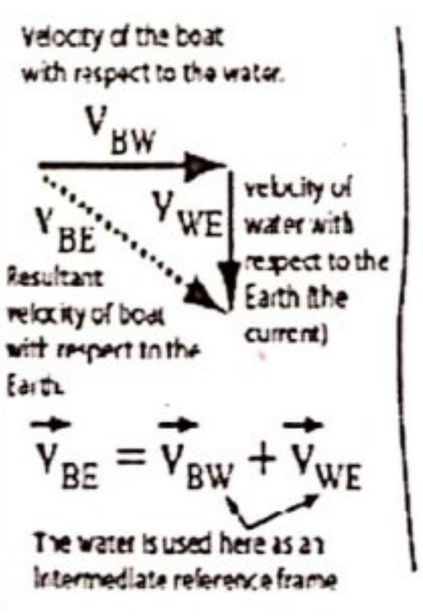
SPEED	VELOCITY
• The ratio of distance covered by a body to the time taken is called speed. • Scalar quantity.	• Time rate of change of displacement is called velocity. • Vector quantity.

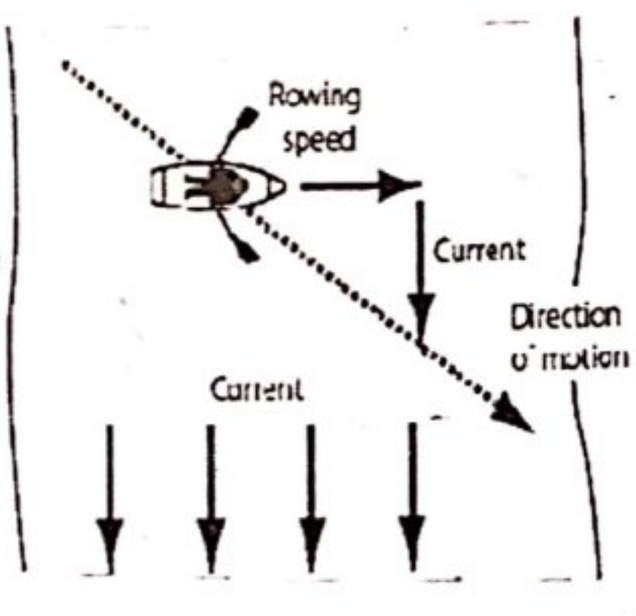
Both have dimensions $[LT^{-1}]$ and are measured in $m\ s^{-1}$

Their classification is as follow:

POINT TO PONDER

- For a body moving with uniform speed, its instantaneous and average speeds are equal to each other.
- A boat in current is a good example of relative velocity.





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ACCELERATION

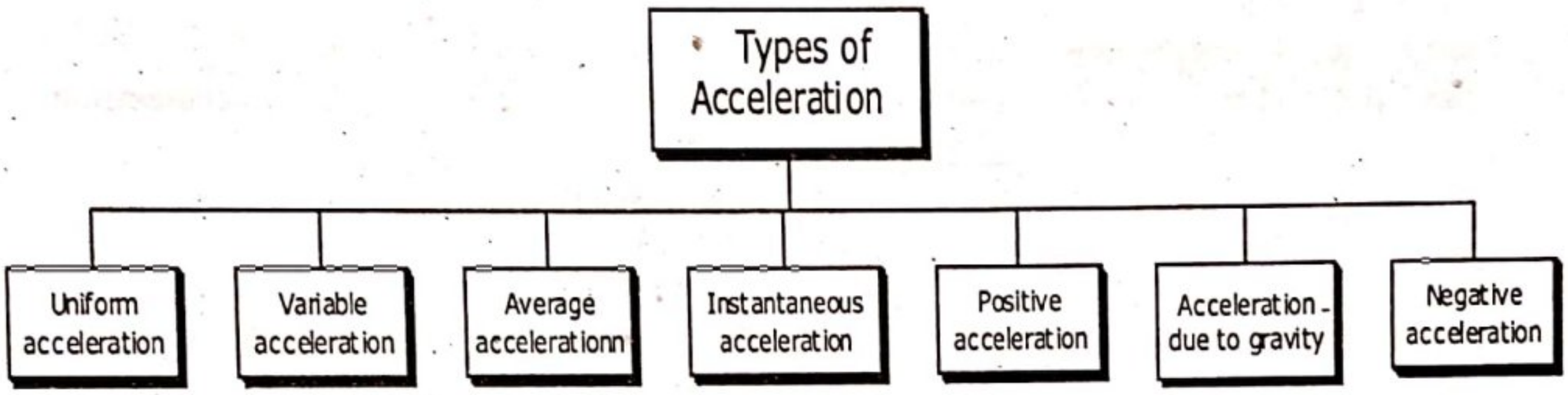
Rate of change of velocity is called acceleration. $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$

- Acceleration may be produced by the variation of:

(a) magnitude of velocity i.e. speed.

(b) direction of velocity.

(c) both magnitude and direction of velocity.



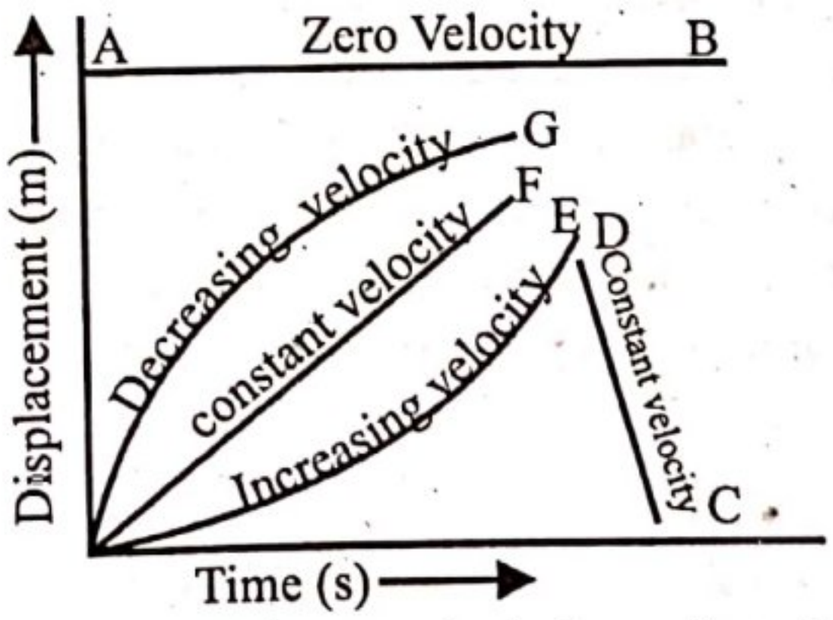
- Acceleration is a vector quantity measured in m s^{-2}. Its dimensions are $[LT^{-2}]$
  If the velocity of body reduces but not to zero, then negative acceleration is called **deceleration** but if the velocity reduces to zero, then negative acceleration is called **retardation.**

GRAPHS

Graph is a pictorial display between two dependent quantities.

Displacement-Time Graph

A graph between displacement and time is called displacement-time graph. From such a graph as show in Fig. we observe



(i) If the graph is straight line (AB) parallel to x-axis, it shows there is no displacement with time or body has zero velocity.

(ii) If it is a straight line inclined to x-axis such as OF, it shows the body is moving with a constant velocity. If this straight line is inclined to x-axis by an angle > 90° (such as CD) it shows body is moving with negative velocity. We can not have straight line parallel to y-axis as it will indicate infinite velocity.

(iii) If the graph is such that its slope keeps on increasing with time (such as OE), the velocity increasing i.e. the motion is accelerated.
If the graph is such that its slope keeps on decreasing with time such as OG, the velocity is decreasing.

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Velocity-Time Graph

A graph plotted between velocity and time is known as velocity-time graph. The shape of graph indicates nature of acceleration as shown in Fig. given below

Salient Features

- The slope of velocity time graph gives acceleration i.e.

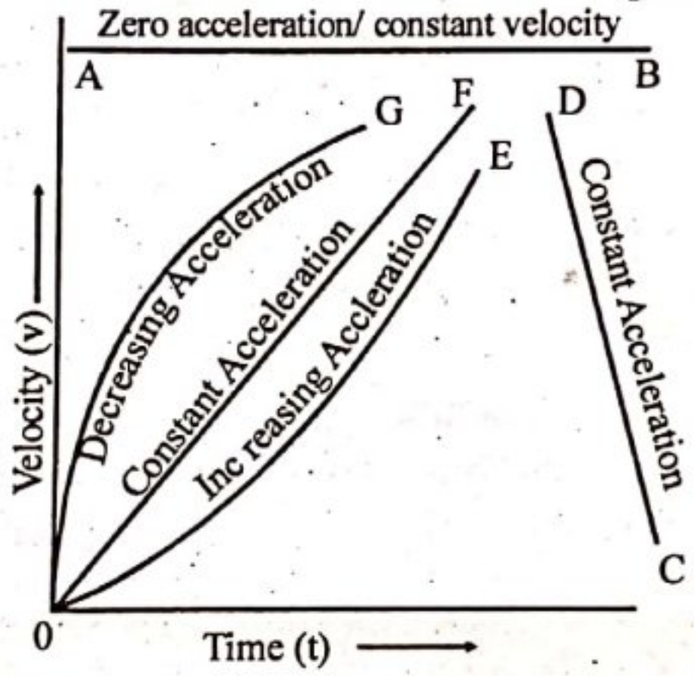
$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \tan\theta = \text{Slope of graph.}$$

(i) Curve AB indicates body is moving with a constant velocity having no acceleration.

(ii) Curve like CD indicates body is moving with constant acceleration but retarded (angle with x-axis > 90).

(iii) Curve like OF where angle < 90 represents constant acceleration accelerated.

(iv) Curve like OG where slope decreases with time it corresponds to decreasing acceleration.



(v) Curve like OE where slope increases with time it corresponds to increasing acceleration.

Some Important Points

- If a body is moving with constant velocity then acceleration (or force on the body) is zero.
- The slope of d – t graph gives velocity.
- The slope of v – t graph gives acceleration.
- If a body falls freely or starts from rest or is dropped $v_i = 0$.
- The velocity and acceleration need not to be in the same direction.
- Velocity and acceleration need not to be zero simultaneously.
- When a body performs journey in two parts of equal distance with speed v_1 and v_2 then average speed $v_{av} = \frac{2v_1v_2}{v_1 + v_2}$
- When a body performs journey in two parts of equal time with speed v_1 and v_2 then average speed $= \frac{v_1 + v_2}{2}$
- If the body is thrown upward then it will rise until its velocity becomes zero and will rise to a height $h = \frac{v^2}{2g}$
- If a body travels with a uniform acceleration a_1 for a time interval t_1 and with uniform acceleration a_2 for time interval t_2, then the average acceleration $a = \frac{a_1t_1 + a_2t_2}{t_1 + t_2}$

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- A body thrown upwards takes same time for going up (till its velocity becomes zero) as it takes to come down and comes back with the same velocity with which it was throw upward.
- When a body is dropped freely from the top of building and another body is projected horizontally from the same point, both will reach the ground at the same time.
- Time taken to reach earth by a freely falling body from the same height is independent of mass (neglecting air effects).
- For a body projected upwards, the magnitude of velocity at any point in its path is same whether the body is moving upwards or downwards.

EQUATIONS OF MOTION (BY GALILEO)

$v_f = v_i + at$ or $v_f = v_i + gt$

$s = v_i t + \frac{1}{2} at^2$ or $s = v_i t + \frac{1}{2} gt^2$

$v_f^2 = v_i^2 + 2as$ or $v_f^2 = v_i^2 + 2gs$

- Distance traveled in nth second with constant acceleration is $s_n = v_i + \frac{1}{2} a(2n-1)$

NEWTON'S LAWS OF MOTION

- Newton's work on physics in his book named **PRINCIPIA of mathematics.**
- Newton's laws applicable for moving objects having speed not comparable to the speed of light.

1st law (law of inertia)

First Law of Motion (Law of Inertia): It states that every body continues to be in state of rest or of uniform motion along a straight line unless it is compelled to change that state by an applied force.

- This law qualitatively defines the force.
- The inability of the body to change its state is called inertia. So, it is also known as the law of inertia of Galileo.
- Inertia resists change in the state of motion of the body.

Second Law of Motion (Force and Acceleration):

The effect of an applied force on a body is to cause it to accelerate in the direction of the force. The acceleration is in direct proportion to the force and is inversely proportional to the mass of the body.

OR

A force F acting on a body is equal to its change in momentum per second

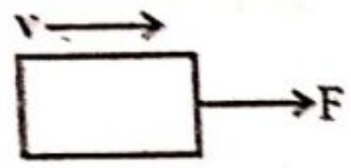
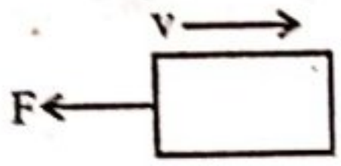
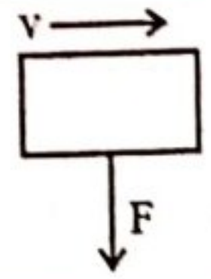
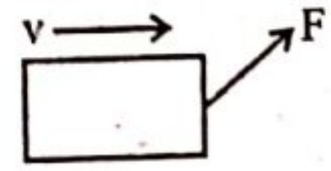
$F \propto$ Mass of the body x Change in velocity per second $\propto ma$

$\therefore \quad F = k\,ma$ (where k is a constant)

But $k = 1$ $\therefore$ **$F = ma$**

- Weight: The weight of a body is equal to the force with which the body is attracted by the earth towards its center.

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When force acts in direction of velocity	When force acts opposite to direction of velocity	When force acts perpendicular to direction of velocity	When force acts at some angle to the direction of velocity
			
Speed increases and direction of motion remain same	Speed decreases and direction of motion remain same	Only direction changes and magnitude of velocity remain same	Both magnitude and direction of velocity changes

3rd law:

$\vec{F}_{AB} = -\vec{F}_{BA}$ or $\vec{F}_{action} = -\vec{F}_{reaction}$

Action and reaction forces never acts on the same body.

INERTIAL AND NON-INERTIAL FRAME

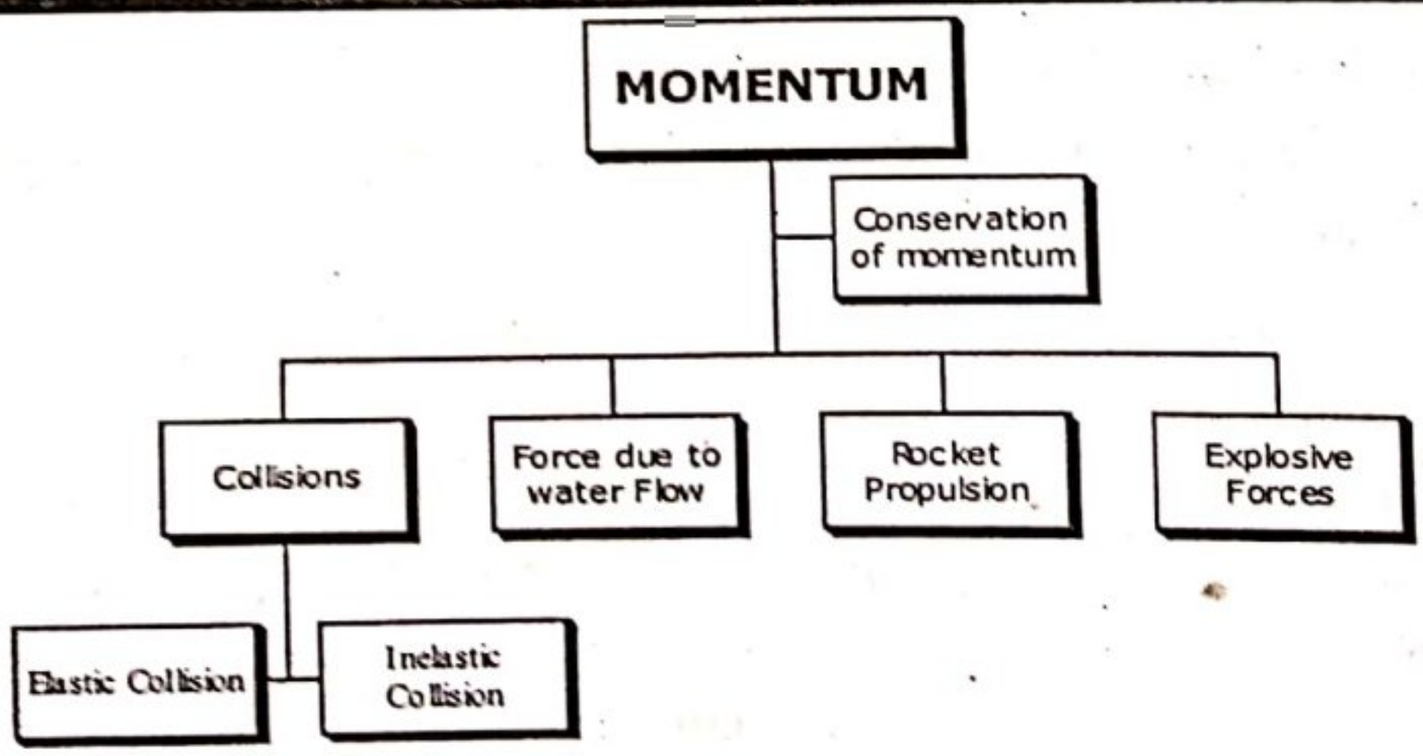
Inertial Frame

It is the frame in which the body is at rest or moving with uniform relative velocity. Law of inertia hold in these frames. $\left(\vec{a} = \vec{0}\right)$.

Non Inertial Frame

It is the frame which is not moving with uniform relative velocity. Law of inertia not hold in these frames. $\left(\vec{a} \neq \vec{0}\right)$.

MOMENTUM



Linear momentum

"The idea of linear momentum was introduced by Newton who defined it as product of mass and velocity of an object". $\vec{p} = m\vec{v}$

- Linear momentum is a vector pointing along velocity
- Linear momentum depends upon $\vec{p} \alpha \vec{v}$ $\vec{p} \alpha m$
- $\vec{p} = 0$ if $\vec{v} = \vec{0}$, how massive the body may be.
- SI unit of linear momentum are kg m s^{-1} or Ns. Dimension of momentum are $[MLT^{-1}]$

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IMPULSE

We define impulse of force as; "The product of force and its duration of application"

$\vec{I} = \Delta\vec{p} = \vec{F}\Delta t$

- Dimensionally $\vec{I}$ is same that of linear momentum.
- Inertial mass is quantitative measurement of acceleration produced.
- Time rate of change of momentum is equal to the applied force.
- Change in momentum is equal to the impulse of the body.

POINT TO PONDER

The thermo pore pieces inside the dinner sets protect the cups or other items from fracturing. Why?

LAW OF CONSERVATION OF LINEAR MOMENTUM

In an **isolated** system $(P_i)_{total} = (P_f)_{total}$

$$m_1v_1+m_2v_2 = m_1 v_1^{'} + m_2 v_2^{'}$$

- The total linear momentum of an isolated system remains constant.

COLLISIONS

Collision is said to be taken place if some sort of interaction appears between bodies due to their closeness.

COLLISIONS

Elastic collisions (K.E and linear momentum both are conserved)	*Inelastic collisions* (only linear momentum is conserved)

Elastic Collision in One Dimension

- Elastic collision in one dimension is that one, in which colliding bodies do not deviate from their line of motion, after the collision.
- In case of two bodies undergoing elastic collision in one dimension, we have

$$v_1 + v_1^{'} = v_2 + v_2^{'} \qquad \text{or} \qquad v_1 - v_2 = -\left(v_1^{'} - v_2^{'}\right)$$

Speed of approach = Speed of recession

After collision,

$$v_1^{'} = \frac{(m_1 - m_2)v_1}{(m_1 + m_2)} + \frac{2m_2v_2}{(m_1 + m_2)}$$

$$v_2^{'} = \frac{2m_1v_1}{(m_1 + m_2)} + \frac{(m_2 - m_1)\,v_2}{(m_1 + m_2)}$$

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Cases of elastic collision

Case I	If	$m_1=m_2$	&	$v_2 \neq 0$
	then	$v'_1=v_2$	&	$v'_2=v_1$
Case II	If	$m_1=m_2$	&	$v_2 = 0$
	then	$v'_1=0$	&	$v'_2 = v_1$

In both cases I & II due to the same masses of the colliding bodies their velocities after collision got interchanged.

Case III	If	$m_1>>m_2$	&	$v_2=0$
	then	$v'_1=v_1$	&	$v'_2=2v_1$
Case IV	If	$m_1<<m_2$	&	$v_2=0$
	then	$v'_1= -v$	&	$v'_2=0$

FORCE DUE TO WATER FLOW

Water exerts force on a wall, when impinges over it. This force is equal to the product of mass flow rate of water and its velocity.

i.e. $\vec{F} = \frac{m}{t}\vec{v}$

The above phenomenon gives us an idea to invent turbines that uses hydral energy.

MOMENTUM & EXPLOSIVE FORCES

Conservation of linear momentum decides in which direction, various pieces will fly from an exploding bomb.

- During explosion law of conservation of momentum holds well. The recoil velocity of a rifle (M,v) fired from a bullet (m,v) is $v' = -\frac{m}{M}v$
- Recoil velocity is always a fraction of the bullet velocity because M>m.

PROPULSION OF ROCKET

- Propulsion of rocket is according to law of conservation of linear momentum
- **80%** mass of rocket consists of fuel at the launching time.
- A typical rocket consumes about 10,000 Kg fuel in one second.
- Speed of gases expelled from the tail of rocket is over 4000 m/s.
- Instantaneous acceleration in the rocket is a= mv/M

Where

m = mass of the gases ejected per second

M = mass of the rocket

v = velocity of ejected gases

POINT TO PONDER

The rockets are made in several compartments. When a compartment is emptied from fuel it is dropped, thus reducing the overall mass of rocket and hence increasing the acceleration of rocket.

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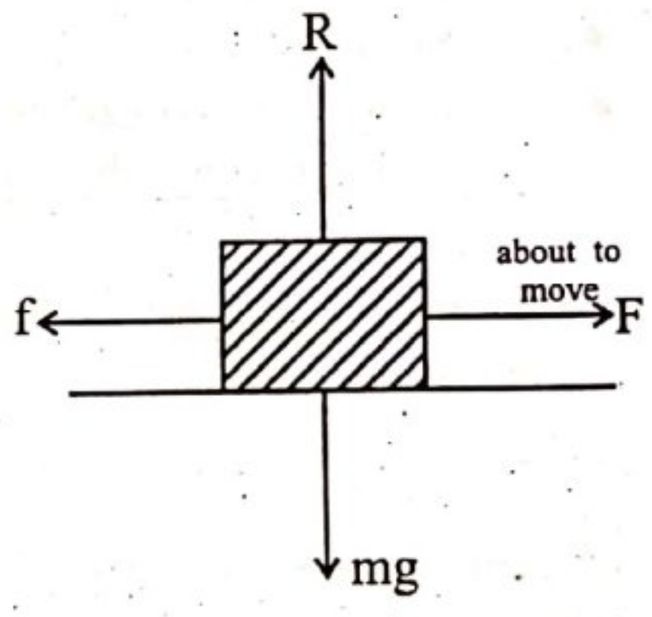
FRICTION

- The property by virtue of which a resisting force is created between two rough bodies which resists the sliding of one body over the other is called friction.
- The force always acts in the direction opposite to that in which the body has a tendency to slide or move.
- The maximum frictional force between two surfaces depends on
  - ✦ Nature of surfaces
  - ✦ Normal contact force
  - ✦ But is independent of the area of contact over wide limits.
- When the body starts moving the force of friction decreases.
- In practice friction can not be zero.
- When we walk on ground then the direction of force of friction is in forward direction because the tendency of slipping is in backward direction.
- Frictional force appears due to interlocking between two surfaces developed due to the molecular irregularities. According to modern view the cause of friction is largely due to atomic and molecular forces of attraction between the two surfaces at the point of contact.
- Coefficient of friction $(\mu) = \dfrac{\text{Limiting friction } (f)}{\text{Normal reaction } (R)}$

  or $\mu = \dfrac{f}{R}$ or $\mathbf{f = \mu R}$
- The coefficient of friction, depends on, nature of material, surface finish, surface film and temperature.
- For horizontal surface

  $R = mg$

  Then $f = \mu mg$



- **Static Friction:** The force of friction that comes into play between two surfaces in contact before the actual motion starts is called static friction.

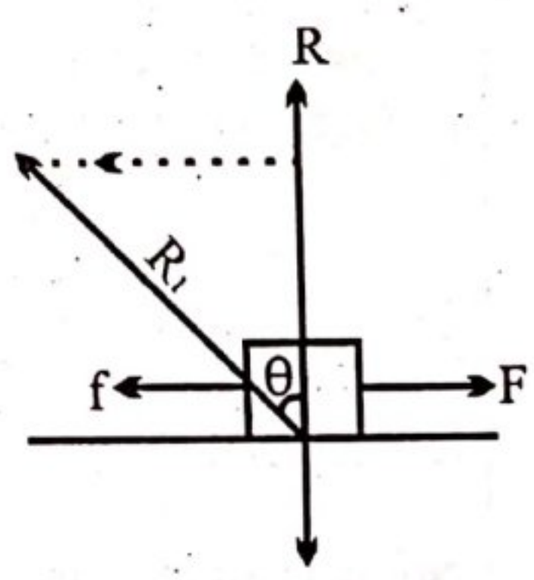
  Force of Static Friction is given by

  $\mathbf{f_s = \mu_s R}$, μ_s is coefficient of static friction
- **Kinetic friction:** when one body moves over the other then the force of friction acting between two surfaces is called kinetic friction.

  Force of kinetic friction is given by

  $\mathbf{f_k = \mu_k R}$, μ_k is coefficient of kinetic friction
- **Limiting friction:** The maximum force of friction which comes into play before a body just **begins** to slide over the surface of another body is called limiting friction.
- **Angle of friction (θ):** Angle which the resultant (R_1) of normal reaction (R) and limiting friction (f) make with the normal reaction is called angle of friction.

  From Figure $\tan\theta = \dfrac{f}{R} = \mu$ or $\mu = \tan\theta$



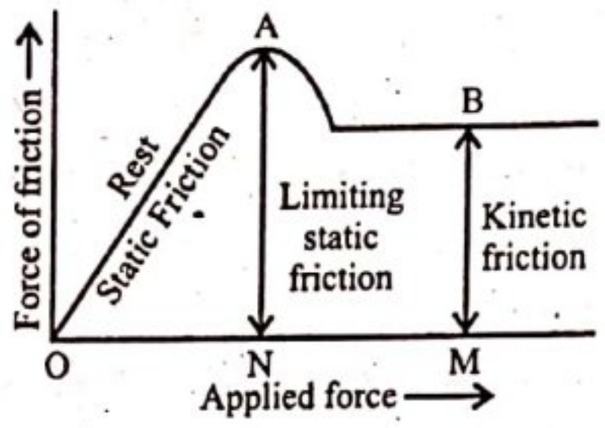
- **For static friction:** $\tan\theta_s = \dfrac{f_s}{R} = \mu_s = \tan\theta_s$

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- **For kinetic friction:** $\tan\theta_k = \frac{f_k}{R} = \mu_k = \tan\theta_k$
- **Rolling Friction:** When one body rolls over the other body, then the frictional force acting between the two surfaces is called rolling friction.

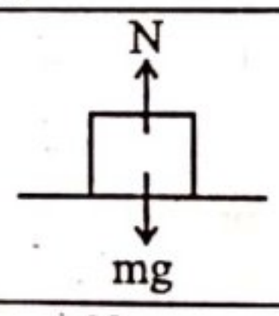
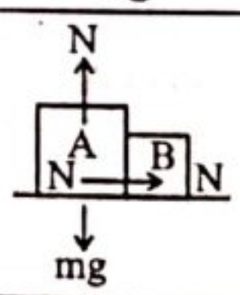
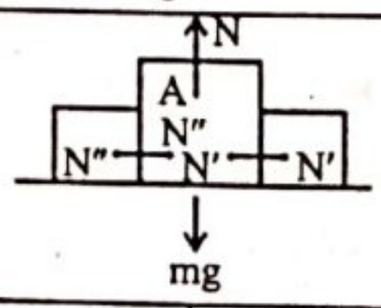
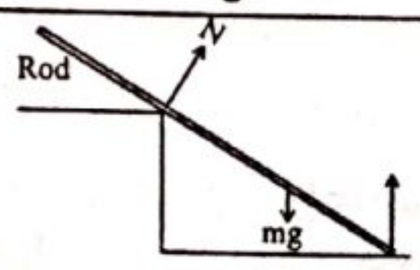
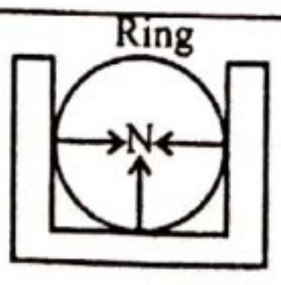
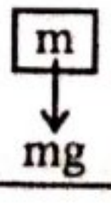
Note: *For the same two surfaces* $\mu_s > \mu_k > \mu_r$

Graph for frictions



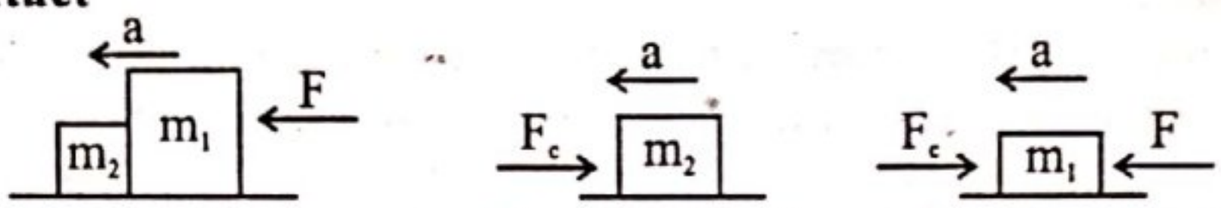
NORMAL CONTACT FORCE

- Two bodies are said to be in contact when there is atleast a force perpendicular or parallel to the surface of contact or point of contact which is related to the motion of two bodies.
- Few contact forces are here:
  - ✦ Normal contact force
  - ✦ Frictional force
  - ✦ Tension in strings
  - ✦ Spring force
- Number of contact forces on a body: Total number of normal contact or contact force is equal to the total number of surface of contact or point of contact. Such as:

Normal contact force is single because one surface is in contact.	
Normal contact forces on A are two because two surfaces are in contact.	
Normal contact forces on A are three because three surfaces are in contact	
Normal contact forces on rod are two because two points are in contact	
Normal contact forces on ring are three because three points are in contact.	
Here normal contact force is absent because block is in air, i.e., there is no surface of point of contact.	

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1) Masses in Contact

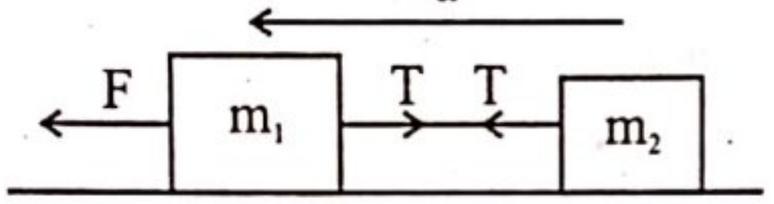


F = Horizontal force applied on m_1, F_c = Contact force, a=Acceleration of the mass

Newton's second law gives: $F - F_c = m_1 a$ and $F_c = m_2 a$

Solving these, we get: $F_c = \frac{m_2 F}{m_1 + m_2}$ and $a = \frac{F}{m_1 + m_2}$

2) Masses Connected by Strings

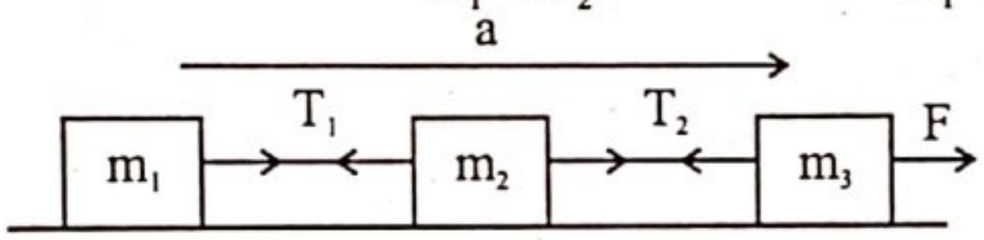


F = Force by which m_1 is pulled, T = Tension developed in the string, a = Acceleration of the masses

Applying Newton's law: $F - T = m_1 a$, $T = m_2 a$

Solving these, we get: $T = \frac{m_2 F}{m_1 + m_2}$ and $a = \frac{F}{m_1 + m_2}$

Similarly,



Applying Newton's law: $F - T_2 = m_2 a$, $T_2 - T_1 = m_2 a$, $T_1 = m_1 a$

Solving these, we get

$$a = \frac{F}{m_1 + m_2 + m_3}$$

$$T_2 = \frac{(m_1 + m_2)F}{m_1 + m_2 + m_3}$$

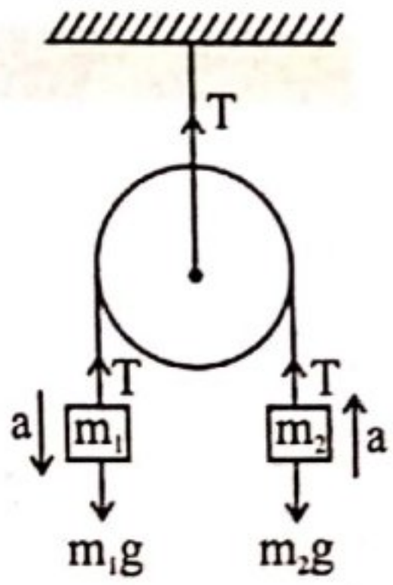
$$T_1 = \frac{m_1 F}{m_1 + m_2 + m_3}$$

Tension and Acceleration in a String

Case 1:

Vertical motion of two bodies attached to the ends of string that passes over a frictionless pulley.

Masses Connected by a String passing Over a Pulley: It $m_1 > m_2$, then m_1 will move downwards and m_2 will move upwards, both with the same acceleration a



Applying Newton's second law:

$m_1 g - T = m_1 a$ **and** $T - m_2 g = m_2 a$

Solving these, we get:

$$a = \frac{m_1 - m_2}{m_1 + m_2} g$$

$$T = \frac{2 m_1 m_2}{m_1 + m_2} g$$

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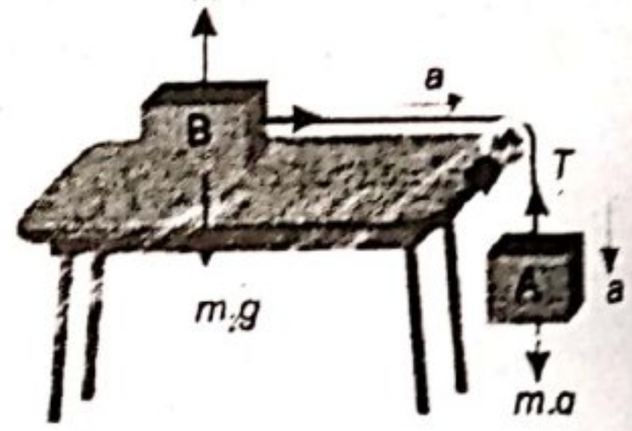
- **Atwood Machine:**

  It is an arrangement of two objects of unequal masses. Both objects are attached to the ends of a string and string passes over a frictionless pulley as shown in figure above. It is used to find the acceleration due to gravity

$$g = \frac{m_1 + m_2}{m_1 - m_2} a$$

Case 2:

When one body moves vertically and other moves horizontally:



- **Acceleration:**

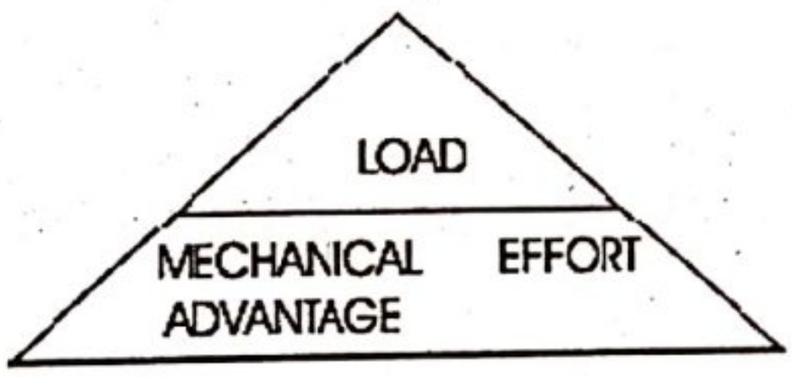
$$a = \frac{m_1 g}{m_1 + m_2}$$

- **Tension:**

$$T = \frac{m_1 m_2 g}{m_1 + m_2}$$

Mechanical Advantage:

Mechanical advantage is defined as the ratio of load to effort.



$$\text{MECHANICAL ADVANTAGE} = \frac{\text{LOAD}}{\text{EFFORT}}$$

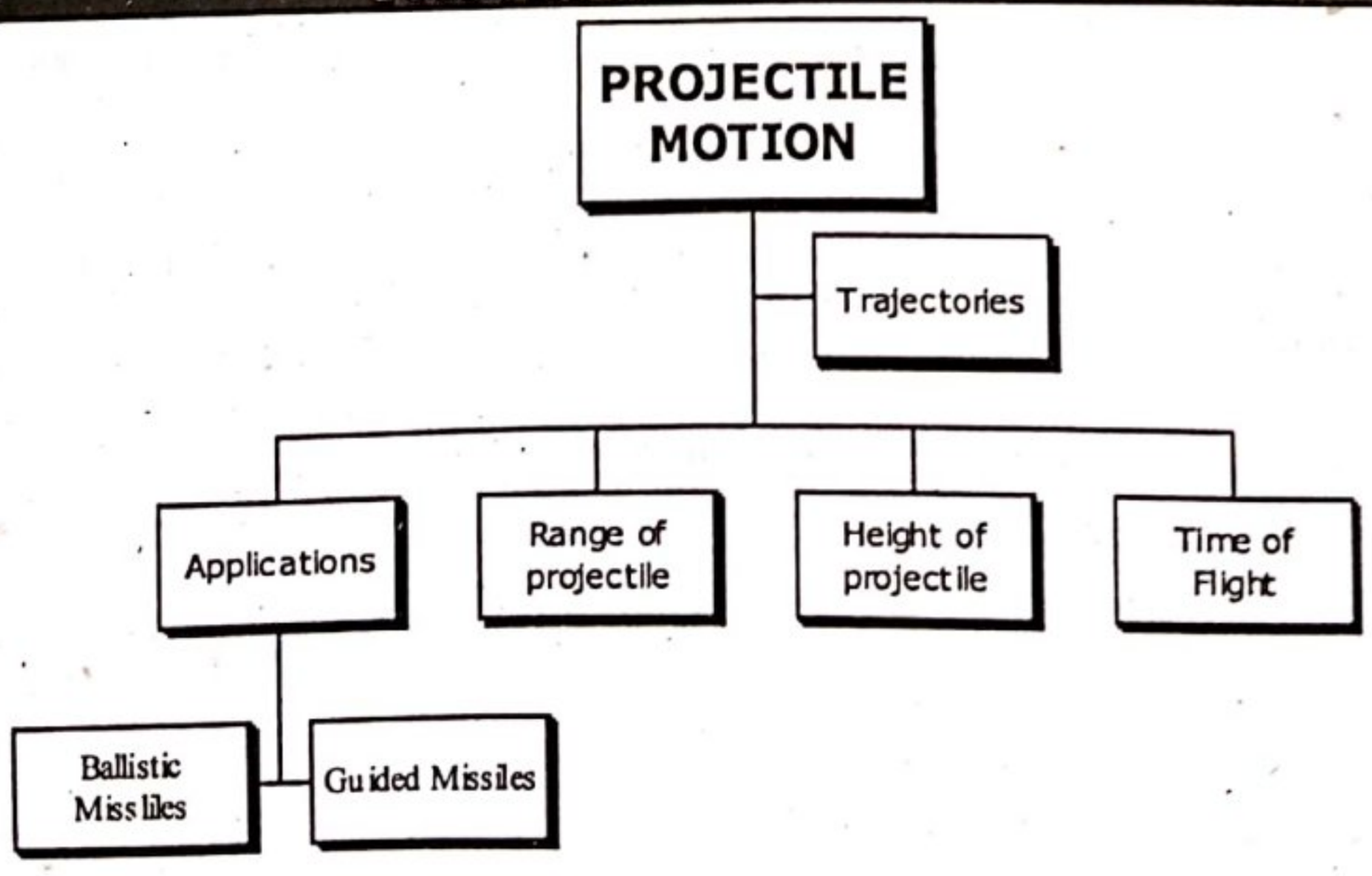
$$\text{LOAD} = \text{MECHANICAL ADVANTAGE} \times \text{EFFORT}$$

$$\text{EFFORT} = \frac{\text{LOAD}}{\text{MECHANICAL ADVANTAGE}}$$

Assumptions for the Derivation of Equations of Projectile

- Earth is assumed to be flat over the whole trajectory of projectile.
- The acceleration due to gravity remains constant over the whole trajectory of projectile.
- Neglecting the aerodynamic effects.

PROJECTILE MOTION



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- Instantaneous velocity is maximum at point of projection and at the landing point and minimum at maximum height as $v_y=0$, at maximum height.
- Horizontal component of projectile velocity remains constant throughout the projectile motion.
- Vertical component decreases, becomes zero at maximum height and then increases till projectile hits the ground.

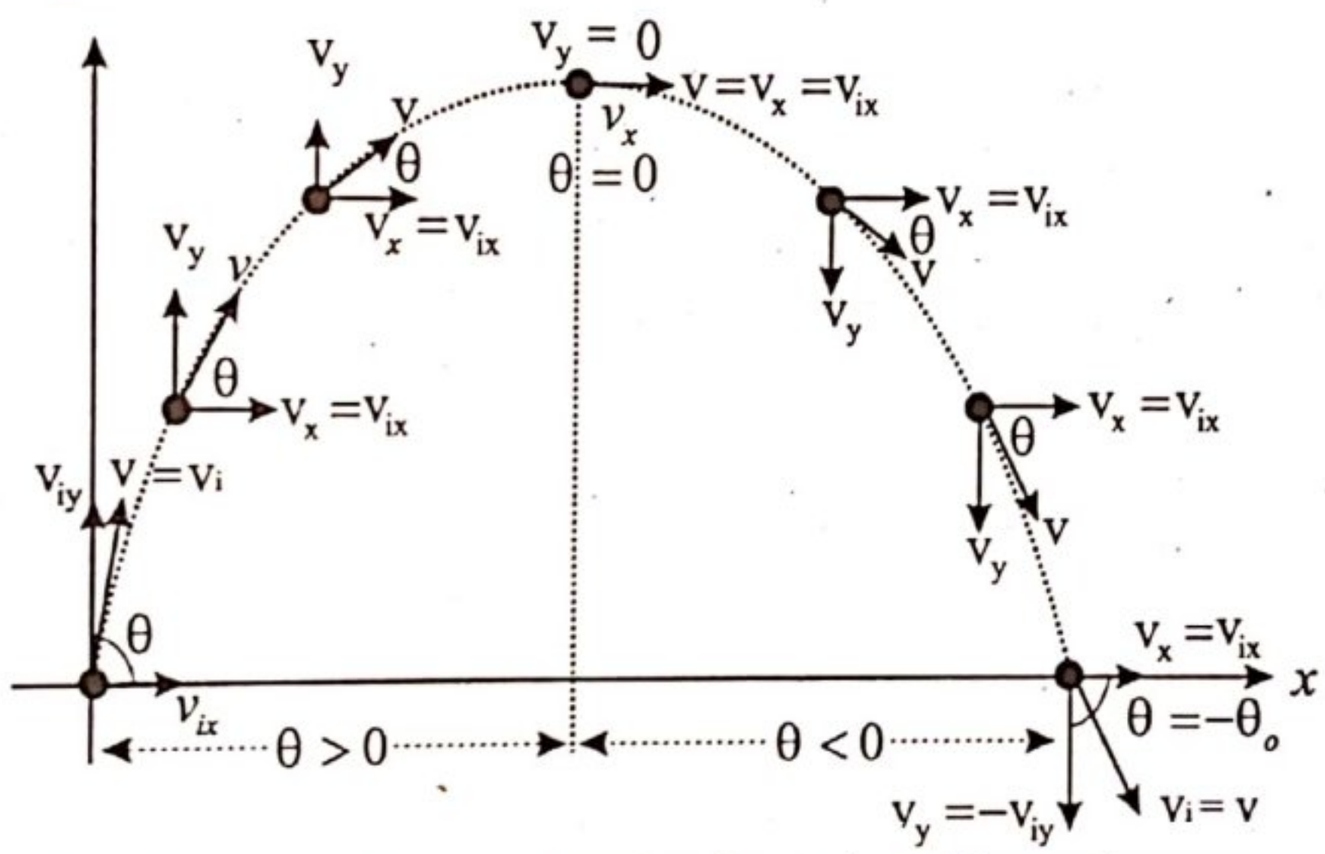
Assumptions for the Derivation of Equations of Projectile

- Earth is assumed to be flat over the whole trajectory of projectile.
- The acceleration due to gravity remains constant over the whole trajectory of projectile.
- Neglecting the aerodynamic effects.

Note that: R = Range of projectile

$a_x = 0$

$a_y = -g$ H = Maximum Height of projectile



- Horizontal and vertical coordinates of projectile at time 't' are given as;

  $x = v_o \cos\theta_o \, t$

  $y = v_o \sin\theta_o \, t - \frac{1}{2} g t^2$

- Trajectory of projectile is parabola in the absence of air friction. In the presence of air friction, it is like parabola.
- If two identical balls are thrown simultaneously from same height, one vertically and other horizontally, then both falls to the earth simultaneously.
- Time to reach maximum height is given as;

  $$t = \frac{v_o \sin\theta_o}{g}$$

- Total time of flight is given as;

  $$T = \frac{2v_o \sin\theta_o}{g}$$

- Vertical range (height) is given as;

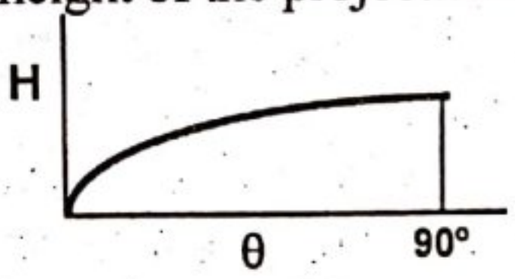
  $$H = \frac{v_o^2 \sin^2\theta_o}{2g}$$

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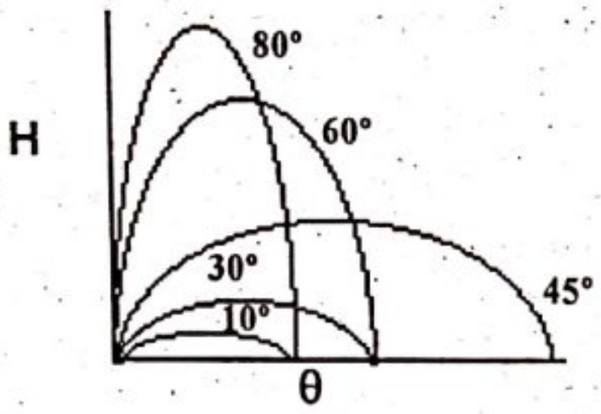
- Range (horizontal) is a distance between point of projection and point at which it comes back to its level of projection. It is given as;

$$R = \frac{v_o^2 \sin 2\theta_o}{g} = \frac{v_o^2 (2\sin\theta_o \cos\theta_o)}{g}$$

- Maximum horizontal range is at angle $\theta = 45°$ and given as; $R_{max} = \frac{v_o^2}{g}$
- The relation between range and the height of the projectile is $\mathbf{R\tan\theta = 4H}$
- Variation of maximum achievable height of the projectile with angle is drawn as below.



- With same initial velocity the range of projectile for two angles of projection will be equal if sum of the angles is equal to 90° i.e. $\theta_1 + \theta_2 = 90°$
- Variation in the range and height with angle of projection is shown with the following sketch for same speed of projection.



POINT TO PONDER

When angle of projection is 76° then range and maximum height of projectile are equal to each other.

Application to Ballistic Missile

- An **un-powered** and **un-guided** missile is called ballistic missile
- Friction of air effects the horizontal and vertical motion of the missile
- Ballistic missiles are useful only for short ranges.
- Powered and remote control guided missiles are used for long ranges and **precision.**

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4 CHAPTER WORK AND ENERGY

WORK

- The term 'work' has following meanings;

1. Psychological Meaning:

All kinds of mental or physical activities are called work, but this kind of meanings is not used in physics.

2. Scientific Meaning:

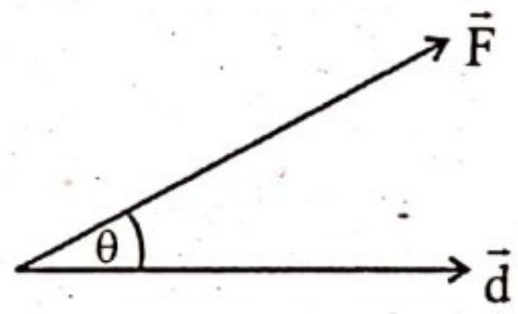
(i) If a force displaces or stops a moving body through a certain distance, the work is said to be done by the force on the body.

(ii) Dot product of force and displacement is called work.

$$W = \vec{F}.\vec{d}$$

$$W = Fd\cos\theta$$

or $W = (F\cos\theta)\,d$ or $W = F(d\cos\theta)$



- **Positive Work**

$\Rightarrow$ For $\mathbf{90° < \theta \leq 180°}$, work done is positive.

$\Rightarrow$ Maximum positive work is done if $\theta = \mathbf{0°}$

Example when an engine pulls a train.

- **Zero work**

$\Rightarrow$ Work will be zero

(i) when $\theta = \mathbf{90°}$, e.g.centripetal force and tension in pendulum string does not do any work

(ii) when F=0, e.g: boy exerts force on a wall.

(iii) when $\vec{d} = 0$, e.g: car is not moving while its engine is running.

- **Negative Work**

$\Rightarrow$ For $\theta > \mathbf{90°}$, work done is negative.

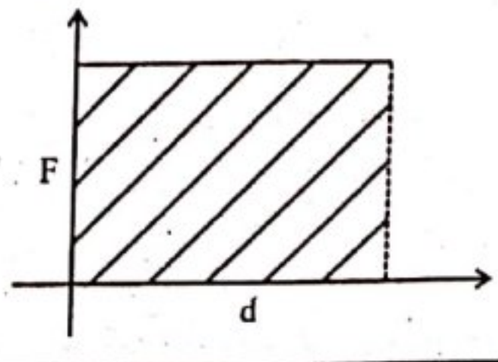
$\Rightarrow$ Maximum negative work when $\theta = \mathbf{180°}$

Example: work done by frictional forces

- SI unit of work is joule (J).
- In particle physics, work is measured in electron volt (eV).
- Dimensionally work is equivalent to $\mathbf{[ML^2T^{-2}]}$.

Graphically work can be obtained from force displacement graph. The area under this graph is work done. Work is a **scalar** quantity.

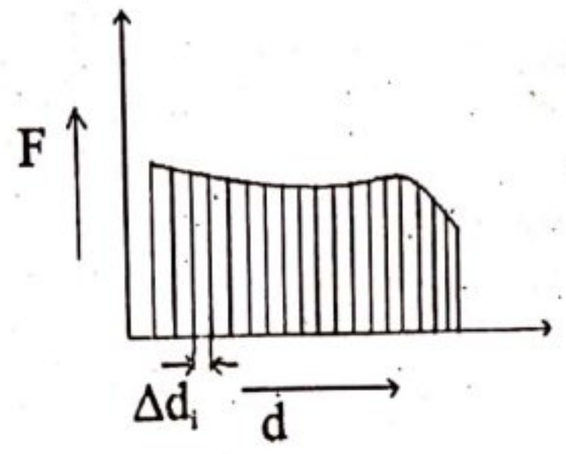
(a) Work done by constant force



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Area = Fd = work done.

(b) Work done by a variable force.



$$\text{Total Area} = \lim_{\Delta d \to 0} \sum_{i=1}^{n} F_i \cos\theta_i \Delta d_i = \text{work done}$$

CONSERVATIVE FIELD

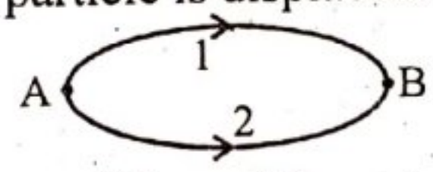
- If a field satisfies following two conditions, it is said to be conservative.

(i) Work done along a closed path is zero i.e. $W_{total} = 0$

(ii) Work done is independent of path followed by body but depends on final and initial position of a body.

Example: Electric field, Gravitational field.

- Frictional force is non-conservative force. Other non-conservative forces are propulsion force on rocket, force of a motor, tension in string etc.
- Spring force F = kx is conservative force.
- Conservative field and conservative force has the property of storing energy in the system. This energy is known as P.E of the system.

CONSERVATIVE FORCES	NON-CONSERVATIVE FORCES
1. The work done by these forces in carrying a particle around a closed path is zero i.e., $W_{total} = 0$.	The work done by these forces in carrying a particle around a closed path is not zero i.e., $W_{total} \neq 0$
2. The work done by these forces in displacing a particle does not depend on the path along which the particle is displaced.  $W_{AB} = W_{BA}$	The work done by these forces depends upon the path along which the particle is displaced. In this case $(W_{AB}) \neq (W_{AB})$
3. Under these forces the kinetic energy of the particle remains constant $K.E_i = K.E_f$ e.g., central forces, gravitational force elastic force, Lorentz force, electrostatic force, magnetic force etc.	Under these forces the kinetic energy of the particle changes $K.E_i \neq K.E_f$ e.g., frictional force, retarding force, viscous force, magnetic force due to an electric current etc. (all these are velocity dependent forces)

POWER

Time rate of doing work is called power.

Power = work/time

- In linear motion, power is given as;

$$P = \frac{W}{t} = \vec{F}.\vec{v}$$

- In angular motion, power is given as;

$$P = \vec{\tau}.\vec{\omega}$$

POINT TO PONDER

A person having more power than other person does not means that he has more energy as well. Reverse is also true.

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- Average power is given as;

$$< P >= \frac{< W >}{t} = F_{av} \frac{d}{t}$$

- Instantaneous power is given as;

$$P = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t}$$

If $<P> = P_{ins}$, then body does work at constant rate.

- Unit of power is watt defined as;

1 W = 1 J/1 sec

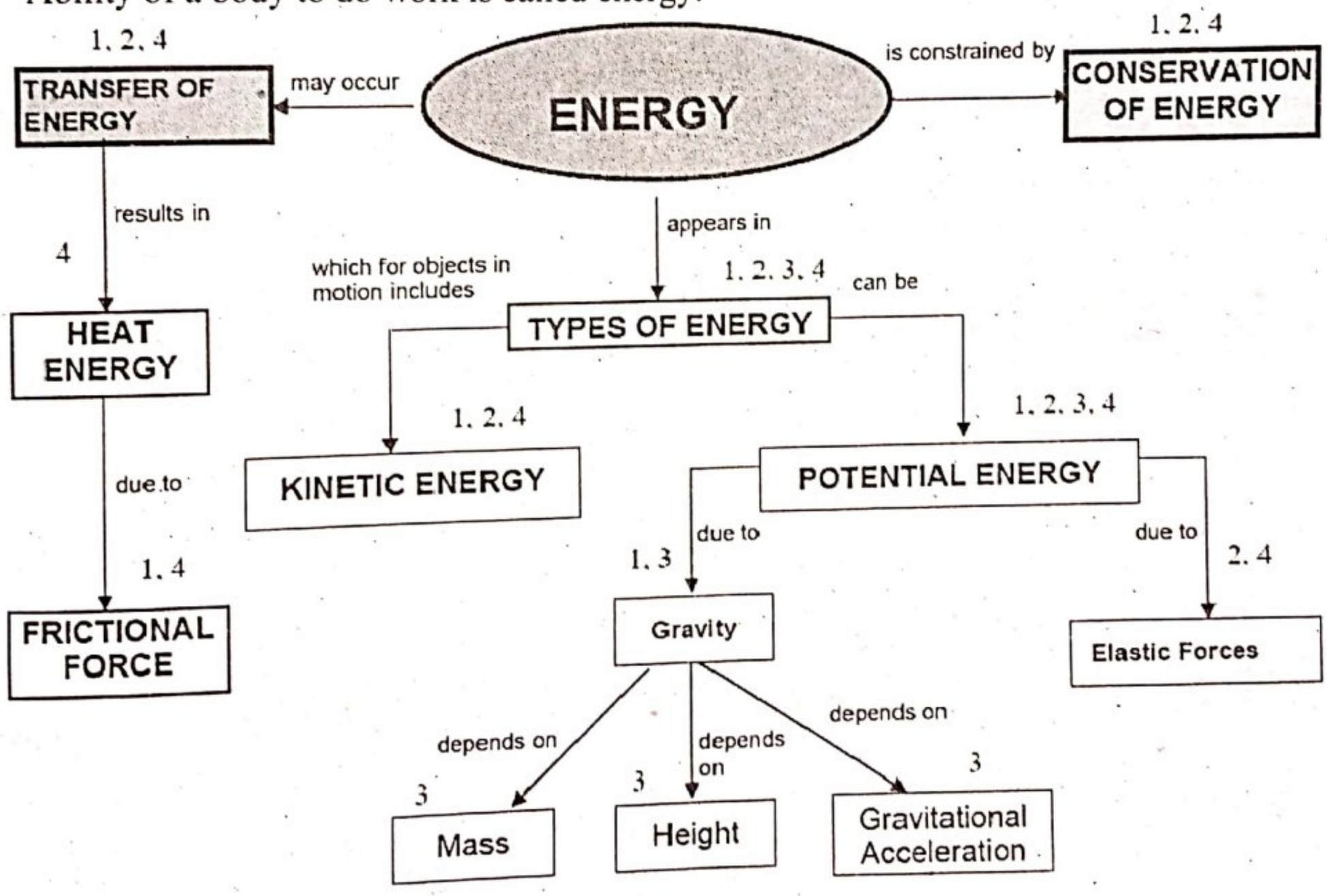
- Dimensionally power is equivalent to $[ML^2T^{-3}]$
- 1 h.p = 746 watt = 550 foot pound/sec
- Commercial unit of electrical energy $1kW\ h = 3.6 \times 10^6\ J$

POINT TO PONDER

If a spring is compressed then work done on it equals the increase in its elastic potential energy.

ENERGY

Ability of a body to do work is called energy.



Forms of energy

NAME	DEFINITION	FORMULA
K.E	Ability of a body to do work due to motion	$1/2\ mv^2 = p^2/2m$ P=momentum
Gravitational P.E	Ability of a body to do work due to position in gravitational field	m g h
Elastic P.E	Ability to do work due to elasticity	$\frac{1}{2}kx^2$
Electric P.E	Ability of a body to do work due to position in electric field	$q\Delta V$

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Work Energy Principle

"Work done on the body equals change in its K.E"

i.e.

$$\text{Work} = (K.E)_f - (K.E)_i$$

APPLICATIONS OF GRAVITATIONAL P.E

- Absolute gravitational P.E of a body on surface of earth is given as

$$U_m = -\frac{GmM}{R}$$

- Negative sign due to selecting the zero reference level of potential energy at infinite distance from earth.
- Due to smaller value of g on Moon, a man can jump **higher** than on earth.
- Due to smaller value of g a man can't run faster on Moon.

POINT TO PONDER

The gravitational force holds inverse square relationship with the distance of the object from the center of earth.

Relation between Momentum and K.E

$$K.E = \frac{P^2}{2m}$$

ESCAPE VELOCITY

The **minimum** initial velocity required by an object on earth to escape from earth's gravitational field.

$$V_{esc} = \sqrt{\frac{2GM_e}{R_e}} = \sqrt{2g_eR_e}$$

Value of V_{esc} $= 11.2 \times 10^3 ms^{-1} = 6.96 \text{miles } s^{-1} = \mathbf{11.2 kms^{-1}}$
$= 25000 \text{ miles } h^{-1} = 40320 kmh^{-1}$

Escape velocity is independent of the mass of the body.

INTER CONVERSION OF K.E AND P.E.

- In absence of air friction we get

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

$$v = \sqrt{2gh}$$

- If a body is dropped from height 'h' to earth's surface in presence of air, then; Loss in P.E = gain in K.E + work done against air friction.
- If a body is thrown vertically upward in gravitational field in the presence of air, then; Loss in K.E = gain in P.E + work done against air friction.

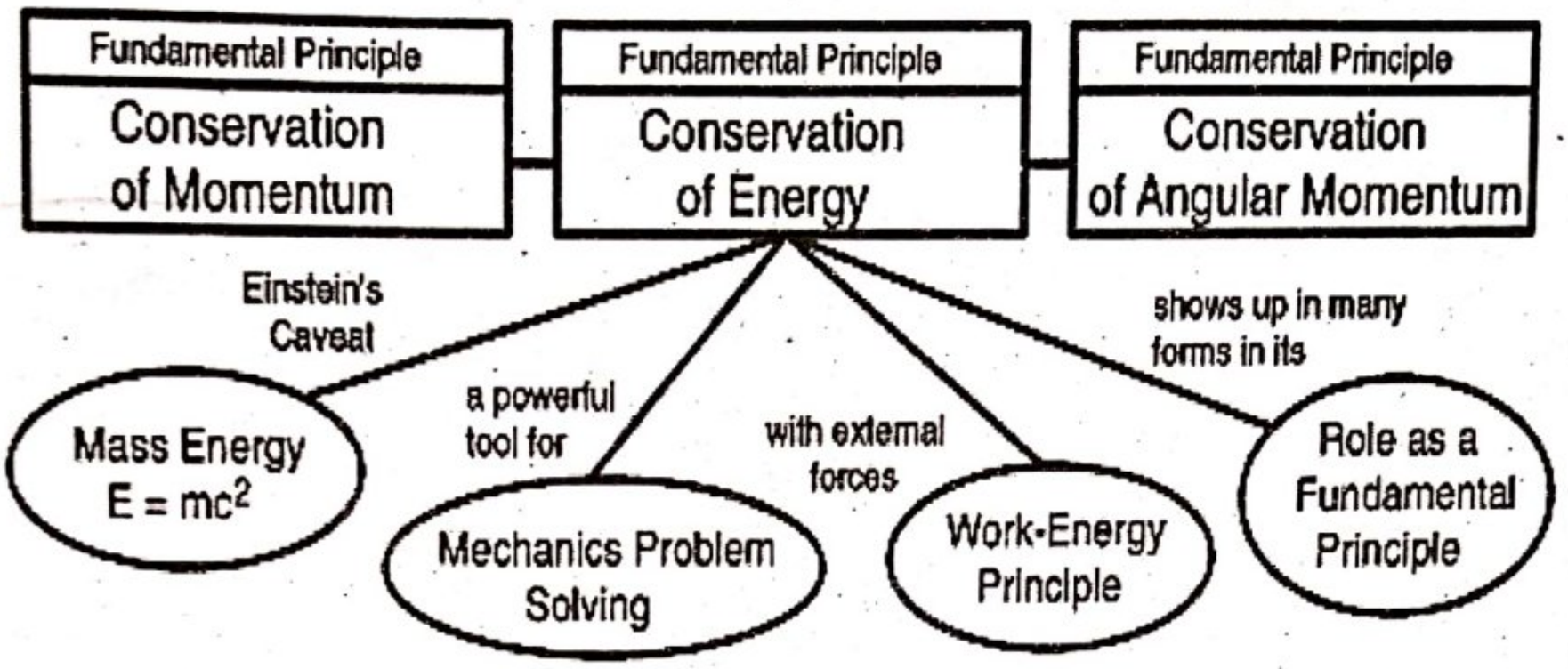
In the absence of air increase in K.E = decrease in P.E. and vice – versa.

CONSERVATION OF ENERGY

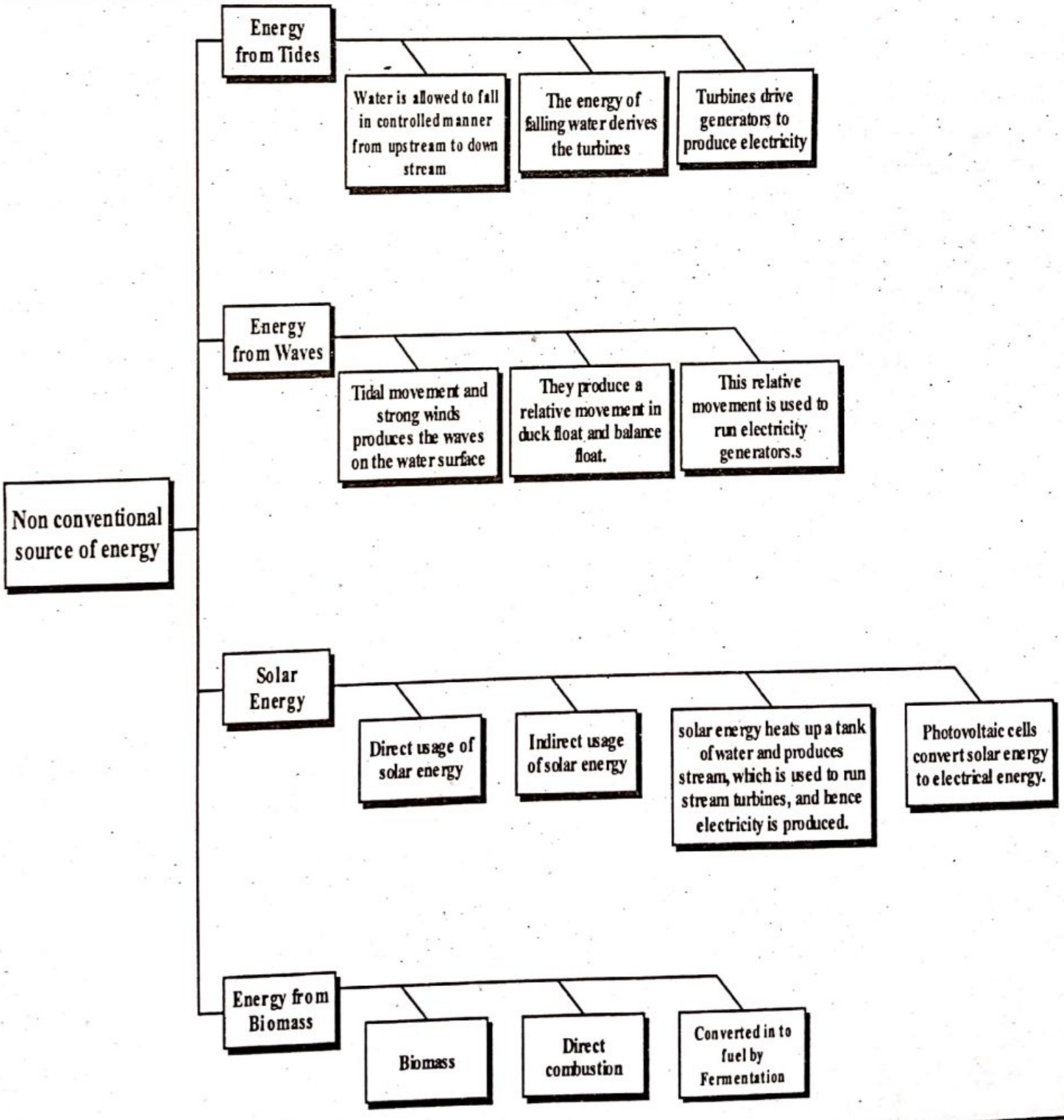
Energy cannot be destroyed. It can be transformed from one form into another, but total amount of energy remain constant.

When a cup is dropped the P.E changes to K.E, but on striking the ground, the K.E changes to heat and sound but total at each instance is always **conserved.**

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NON-CONVENTIONAL SOURCES OF ENERGY



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Energy from Waste Products

Waste is burned in confined containers.

↓

Heat produced is used to generate steam

↓

Steam drives the turbines and produces electricity

POINT TO PONDER

The tides raise the water in the sea roughly twice a day.

- Normal incidence of solar energy outside the earth's atmosphere is about 1.4 kWm^{-2}
- Solar energy reaching on the surface of earth on a clear day at noon is about 1 kWm^{-2}.

POINT TO PONDER

How much energy per sq.m per second is absorbed by atmosphere?

- Ethanol obtained from biomass is a replacement of gasoline.
- Methane obtained from biomass is a replacement of natural gas.
- Annual consumption of energy is about $6x10^{13}kW$.

- Only 0.1% of solar energy is more than total energy required per annum on earth
- Solar panel is series combination of solar cells.
- Solar panels usually have ability to charge nickel-cadmium batteries in artificial satellites.

Sources of geothermal energy

(i) Radioactive decay **(ii)** Residual heat of the earth

(iii) Compression of material in earth

FOR YOUR INFORMATION	
Source of energy	**Original Source**
Solar	Sun
Bio mass	Sun
Fossil fuels	Sun
Wind	Sun
Waves	Sun
Hydro electric	Sun
Tides	Moon
Geothermal	Earth

ENERGY SOURCES	
Renewable	**Nonrenewable**
Hydroelectric	Coal
Wind	Natural gas
Tides	Oil
Geothermal*	Uranium
Biomass	Oil shale
Sunlight	Tar sands
Ethanol/Methanol**	

* Individual fields may run off

** Renewable when made from bio mass

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5 CHAPTER CIRCULAR MOTION

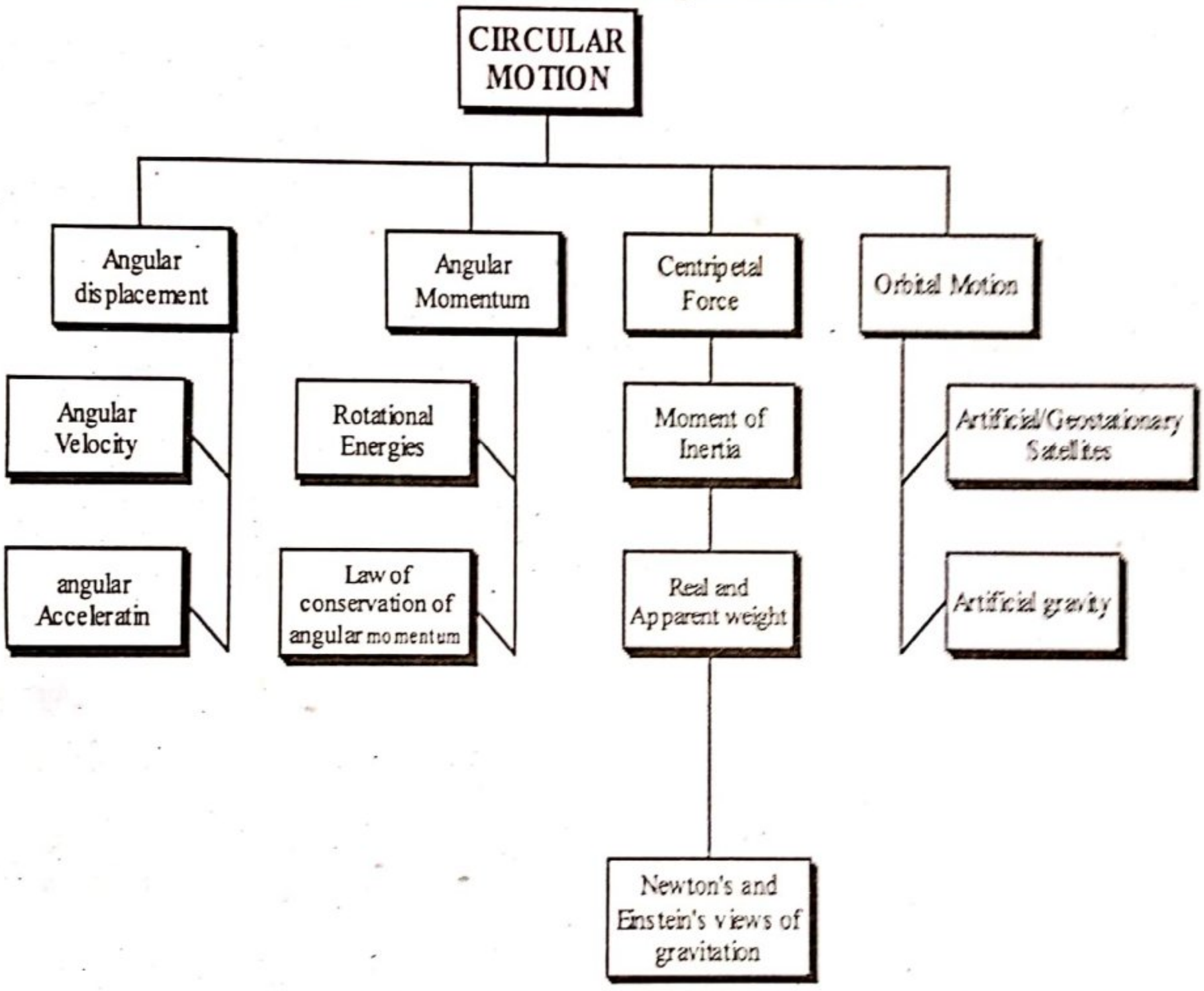
INTRODUCTION

Circular Motion

Motion of bodies in circular path is called circular motion

Angular Moti on

Circular motion of a body may also be called angular motion.



ANGULAR DISPLACEMENT

"It is the angle swept by the radial line during circular motion of a particle measured from some initial point to some final point."

- Angular displacement has direction along axis of rotation and can be determined by right hand rule
- SI unit of angular displacement is radian
- One radian is an angle made by an arc at the center, whose length is equal to the radius of circle.
- Definition of radian gives following useful relation:

POINT TO PONDER

For very small values of angular displacement it is treated as vector quantity.

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$s = r\theta$

$1° = \frac{\pi}{180}$ rad = 0.0174 rad, 1 rad = 57.3°

- Angular displacement is angle in radian or degree covered by body having circular motion.
- Non S.I units are also used which are "degree" and "rev".

ANGULAR VELOCITY & ACCELERATION

- Rate of change of angular displacement is called angular velocity;

$\omega_{av} = \frac{\Delta\theta}{\Delta t}$, usually not a vector quantity.

$\vec{\omega}_{ins} = \lim_{\Delta t \to 0} \frac{\Delta\vec{\theta}}{\Delta t}$, always vector quantity.

POINT TO PONDER

The angular velocity is practically measured in revolution per minute (rpm) as they provide an easy interpretation of angular motion.

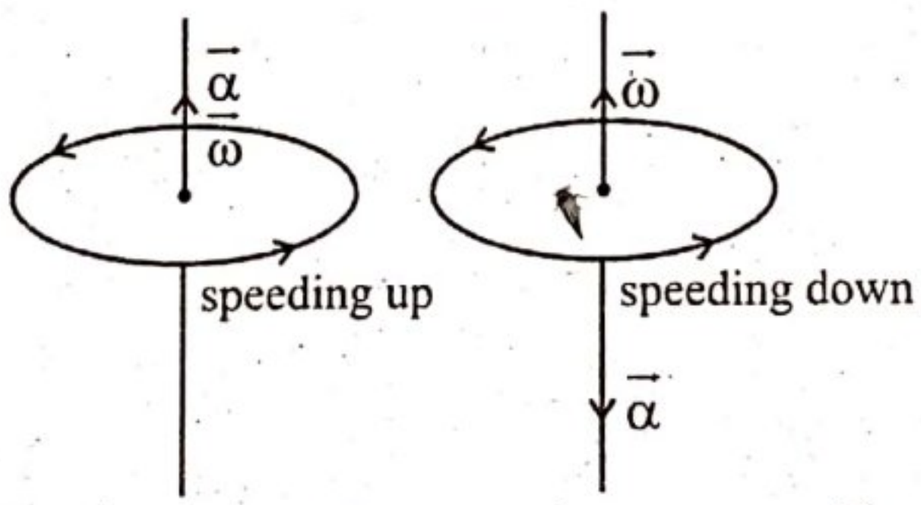
- Tangential and angular velocities are related as:

$v = \omega r$ or $\vec{v} = \vec{\omega} \times \vec{r}$

- S.I unit of angular velocity is rad s^{-1}.
- Rate of change of angular velocity is called angular acceleration.

$\vec{\alpha} = \frac{\Delta\vec{\omega}}{\Delta t}$

- SI unit of angular acceleration is rad s^{-2}
- Angular acceleration is a vector Quantity related to tangential acceleration $\vec{a}$ by the following formula $\vec{a} = \vec{\alpha} \times \vec{r}$
- Direction of angular acceleration and angular velocity is along axis of rotation.



POINT TO PONDER

All the points on a rigid body rotating about a fixed axis have same angular displacement, velocity and acceleration.

- If angular velocity increases, then $\vec{\omega}$ and $\vec{\alpha}$ are in same direction and if angular velocity decreases, then $\vec{\omega}$ and $\vec{\alpha}$ are in opposite direction

Rigid Body

"A body, which maintains a constant distance between its two consecutive particles, when a definite load is applied to it."

Note that all the solid bodies can be treated as rigid in **a specific range of loads** only. e.g. wall is treated to be rigid for a human being but not for hammer.

CENTRIPETAL FORCE & ACCELERATION

The force required to bend a straight line path of a body into the circular path is called centripetal force.

If the centripetal force is removed from the rotating object it will follow a straight-line motion confined on the tangent to that circular path.

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Assumptions

To derive the equations for the centripetal acceleration we assume that speed of the object is constant so that the tangential component of velocity does not produce acceleration but radial component only. The equation is

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}\hat{a}_t + \frac{v^2}{r}\hat{a}_r$$

- In vector form, centripetal force and acceleration can be written as;

$$\vec{F}_c = -mr\omega^2\hat{r} = -m\vec{r}\omega = -\left(\frac{mv^2}{r}\right)\hat{r} = -\left(\frac{mv^2}{r^2}\right)\vec{r}$$

$$\vec{a}_c = -r\omega^2\hat{r} = -\vec{r}\omega = -\left(\frac{v^2}{r}\right)\hat{r} = -\left(\frac{v^2}{r^2}\right)\vec{r}$$

- Work done by centripetal force is zero.
- Centripetal and centrifugal forces form true action & reaction pair but they can't balance each other because they don't act on same body.

COMPARISON OF LINEAR MOTION AND ANGULAR MOTION

ANALOGY BETWEEN TRANSLATORY MOTION AND ROTATORY MOTION

• Linear velocity, $\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$	Angular velocity, $\vec{\omega} = \frac{\Delta \vec{\theta}}{\Delta t}$
• Linear displacement, $\vec{d}$	Angular displacement, $\vec{\theta}$
• Acceleration or linear acceleration, $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$	Angular acceleration, $\vec{\alpha} = \frac{\Delta \vec{\omega}}{\Delta t}$
• Mass, m	Moment of inertia, $I = mr^2$
• Linear momentum, $\vec{P} = m\vec{v}$	Angular momentum, $\vec{L} = I\vec{\omega}$
• Impulse, $I = \vec{F} \times \Delta t$	Angular impulse $= \vec{\tau} \times \Delta t$
• Force, $\vec{F} = m\vec{a} = \frac{\Delta \vec{p}}{\Delta t}$	Torque, $\vec{\tau} = I\vec{\alpha} = \frac{\Delta \vec{L}}{\Delta t}$
• Work, $W = \vec{F}.\vec{d} = \frac{1}{2}m\left(v_2^2 - v_1^2\right)$	Rotational work, $W_r = \tau\theta = \frac{1}{2}I\left(\omega_2^2 - \omega_1^2\right)$
• Kinetic energy, $K.E = \frac{1}{2}mv^2$	Kinetic energy of rotation, $K.E_r = \frac{1}{2}I\omega^2$
• **Newton's laws in linear motion: First law:** If $F = 0$ then $v =$ constant **Second Law:** $\vec{F} = m\vec{a}$ **Third Law:** $\vec{F}_{12} = -\vec{F}_{21}$	**Newton's laws in rotational motion: First law:** If $\tau = 0$ then $\omega =$ constant **Second Law:** $\vec{\tau} = I\vec{\alpha}$ **Third Law:** $\vec{\tau}_{12} = -\vec{\tau}_{21}$
• Equations of linear motion **(i)** $v_f = v_i + at$ **(ii)** $s = v_i t + \frac{1}{2}at^2$ **(iii)** $v_f^2 - v_i^2 = 2as$	Equations of rotational motion **(i)** $\omega_f = \omega_i + \alpha t$ **(ii)** $\theta = \omega_i t + \frac{1}{2}\alpha t^2$ **(iii)** $\omega_f^2 - \omega_i^2 = 2\alpha\theta$

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• Distance covered in nth second $s_n = v_i + \frac{a}{2}(2n-1)$	Angle subtended in nth second $0_n = \omega_i + \frac{\alpha}{2}(2n-1)$
• $s = vt$	$0 = \omega t$
• $<v> = \frac{v_i + v_f}{2}$	$<\omega> = \frac{\omega_i + \omega_f}{2}$

MOMENT OF INERTIA

"The measure of hindrance offered by a rigid body against angular motion, when a disturbing torque acts over the body."

Mathematically expressed as moment of inertia $= I = mr^2$.

It is measured in kg m^2. Moment of inertia depends upon

(i) Mass of the body.

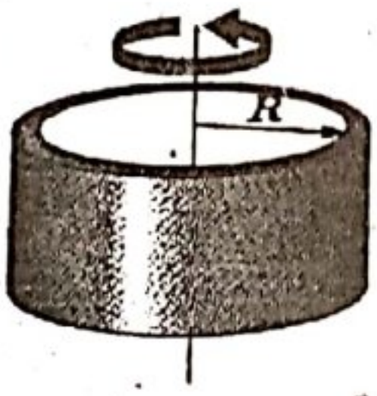
(ii) Distribution of the mass about the axis of rotation.

• Moment of inertia plays same role in angular motion as the mass in linear motion.

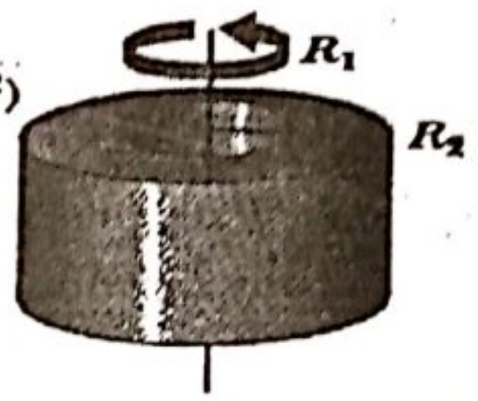
The equation $\tau = I\alpha$ is the rotational analogue of the Newton's second law $F = ma$

Moment of Inertia of Some Regular Bodies

Hoop or cylindrical shell
$I_c = MR^2$



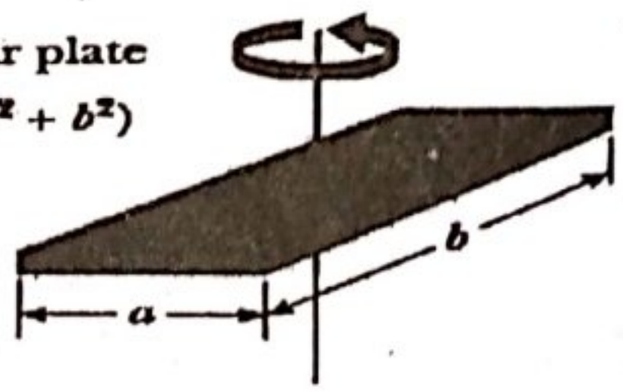
Hollow cylinder
$I_c = \frac{1}{2} M(R_1^2 + R_2^2)$



Solid cylinder or disk
$I_c = \frac{1}{2} MR^2$



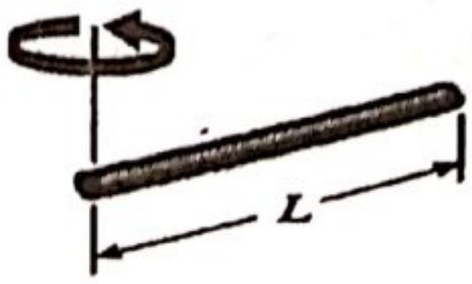
Rectangular plate
$I_c = \frac{1}{12} M(a^2 + b^2)$



Long thin rod
$I_c = \frac{1}{12} ML^2$



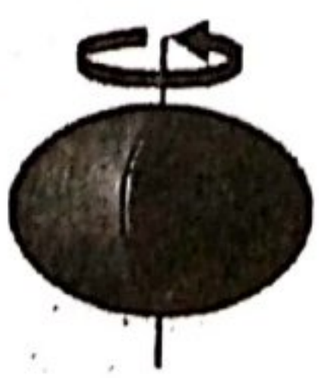
Long thin rod
$I = \frac{1}{3} ML^2$



Solid sphere
$I_c = \frac{2}{5} MR^2$



Thin spherical shell
$I_c = \frac{2}{3} MR^2$

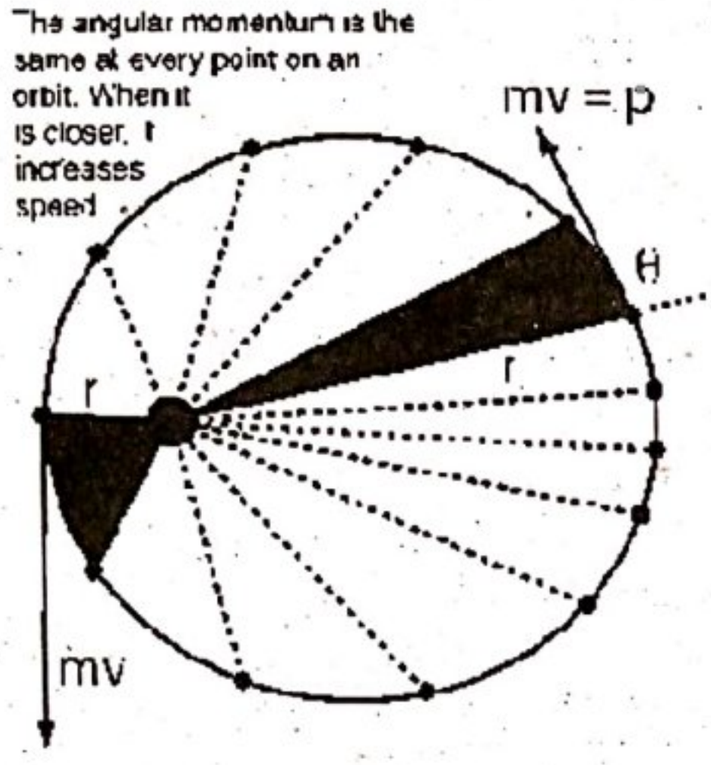


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ANGULAR MOMENTUM

- Angular momentum is due to spin motion or orbital motion of a body, and is also called moment of momentum.

Angular Momentum of a Particle



The angular momentum of a particle of mass m with respect to a chosen axis is given by

$$L = mvr \sin\theta$$

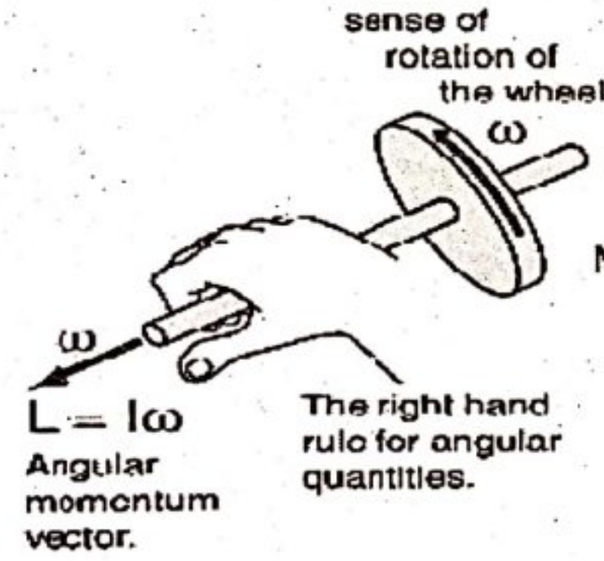
or more formally by the vector product

$$\mathbf{L = r \times p}$$

The direction is given by the right hand rule which would give L the direction out of the diagram. For a circular orbit, $\vec{L}$ becomes L = mvr

Angular Momentum

The angular momentum of a rigid object is defined as the product of the moment of inertia and the **angular velocity.**



Angular Momentum = Moment of Inertia × Angular Velocity

$$L = I \times \omega$$

- Orbital angular momentum is greater than spin angular momentum of an electron.

LAW OF CONSERVATION OF ANGULAR MOMENTUM

Angular momentum is a conserved quantity only in isolated system.

$L_1 = L_2$, $\sum \vec{L}$ =constant if and only if $\sum \tau_{ext} = 0$

OR $I_1 \omega_1 = I_2 \omega_2$

- Total angular momentum of a particle or a system of particle remains constant provided no net external torque acts on it.

Applications

- When a gymnast closes her arms while standing on a rotating joy wheel, the wheel speeds up, and slows down for the reverse just to conserve angular momentum.
- Springboard diver has more rotation when she pulls her body into tuck position.
- Balance of a sport bicycle is maintained due to the conservation of angular momentum for its thin rotating wheels.

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ROTATIONAL K.E

- Rotational K.E is given by

$$K.E_{rot} = \frac{1}{2} I \omega^2$$

- Rotational K.E of disc

$$K.E_{rot} = \frac{1}{4} mv^2 = \frac{1}{2} (K.E_{lin})$$

- Rotational K.E of hoop

$$K.E_{rot} = \frac{1}{2} mv^2 = (K.E_{lin})$$

- Velocity of hoop at the bottom of an inclined plane

$$v = \sqrt{gh}$$

- Velocity of disc at the bottom of an inclined plane

$$v = \sqrt{\frac{4}{3} gh} = \frac{2}{\sqrt{3}} \sqrt{gh}$$

MOTION IN A VERTICAL CIRCLE

- When a body being tied to a string is whirled in a vertical plane, its speed is different at different points of the circular path.
- In such type of motion, the tension in the string and the centripetal force acting on the body go on varying continuously.
- At the highest point A, the tension in the string is T_A and the speed of the body is v_A then

$$\mathbf{T_A + mg = \frac{mv_A^2}{r}}$$ where r is the radius of circular path.

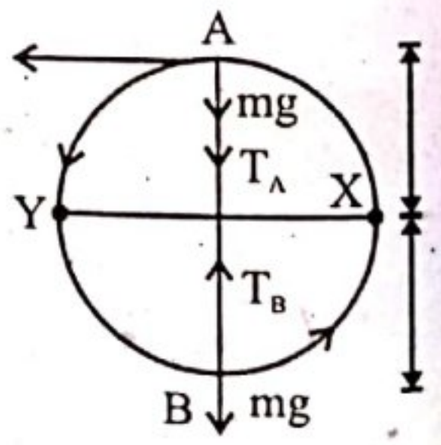
- If $T_A = 0$,

then $mg = \frac{mv_A^2}{r}$

or $v_A = \sqrt{gr}$

This speed of the body is known as critical speed and is denoted by v_c

$$\therefore \quad \mathbf{v_c = \sqrt{gr}}$$



- In case $v_A < v_C$, the body will fall down.
- At the lowest point B, let v_B be the speed of the body and the tension in the string T_B,

so that $T_B - mg = \frac{mv_B^2}{r}$ or $T_B = mg + \frac{mv_B^2}{r}$

- Velocity at point B, $\mathbf{v_B = \sqrt{5gr}}$

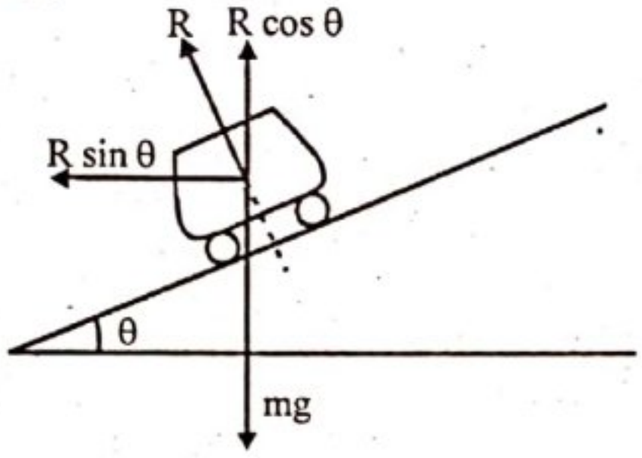
Velocity at point X and Y = $\mathbf{v_X = v_Y = \sqrt{3gr}}$

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BANKING OF CURVED TRACKS

When a vehicle goes round a level curve the necessary centripetal force is provided by the force of friction between the tyres and the track (road or rail track). In case the frictional force, which acts as centripetal force and keeps the body moving along the circular path, is not enough to provide the necessary centripetal force, the vehicle will skid. To avoid the skidding of the vehicle the track is banked in such a way that the outer part of the track is raised a little above the inner side, which makes the track sloping towards the centre of the curve.

The inclination angle θ is chosen in such a way that the horizontal component of the normal reaction provides the centripetal force and the vertical component of the reaction supports the weight (as shown in figure) i.e.



$$R \sin\theta = m v^2/r \quad \ldots (9)$$

and $$R \cos\theta = mg \quad \ldots (10)$$

From (9) and (10) we have

$$\tan\theta = \frac{v^2}{rg} \text{ or } \theta = \tan^{-1}\left(\frac{v^2}{rg}\right) \quad \ldots (11)$$

Under limiting condition i.e. for maximum speed for no skidding $\mu = \tan\theta$, hence.

$$V_{max} = \sqrt{\mu r g} \quad \text{or} \quad V_{max} = \sqrt{\frac{r d g}{2 h}} \quad \ldots (12)$$

where h is the height of the centre of gravity and d is the separation between inner and outer wheels.

QUANTITY	TRANSLATION	ROTATIONAL	RELATION
Displacement	$\vec{d}$	$\vec{\theta}$	$s = r\theta$
velocity	$\vec{v} = \frac{\vec{d}}{t}$	$\vec{\omega} = \frac{\Delta\vec{\theta}}{\Delta t}$	$v = r\omega$
Acceleration	$a = \frac{\Delta v}{\Delta t}$	$\vec{\alpha} = \frac{\Delta\vec{\omega}}{\Delta t}$	$a_T = r\alpha$ $a_r = r\omega^2$
Mass/moment of Inertia	m	$I = mr^2$	$I = \sum mr^2$
Force / Torque	$\mathbf{F} = ma$	$\vec{\tau} = \vec{r} \times \vec{F}$	
Kinetic Energy	$K.E = \frac{1}{2}mv^2$	$K.E_{rot} = \frac{1}{2}I\omega^2$	
Momentum	$\mathbf{p} = mv$	$L = I\omega$	$\vec{L} = \vec{r} \times \vec{p}$
Power	$P = \mathbf{F}.\mathbf{v}$	$P = \tau\ \omega$	
Work	$W = \mathbf{F}.\mathbf{d}$	$W = \tau . \Delta\theta$	
Impulse	$\mathbf{I} = \mathbf{F}\Delta t$	$\mathbf{I} = \tau\ \Delta t$	
Equilibrium	$\sum\vec{F} = \vec{0}$	$\sum\vec{\tau} = \vec{0}$	

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Universal Gravitation: $F = G\frac{m_1 m_2}{r^2}$

Acceleration due to gravity: $g = \frac{GM}{R^2}$

$g = \frac{G}{R^2}\left(\frac{4}{3}\pi R^3 \rho\right)$ As mass (M) = volume $\left(\frac{4}{3}\pi R^3\right) \times$ density (ρ)

Hence $\mathbf{g = \frac{4}{3}\pi\rho GR}$

VARIATIONS in g

- **Variation in g above the surface of earth**

$g = \frac{GM}{R^2}$.....(i) Or $g' = \frac{GM}{(R+h)^2}$.....(ii)

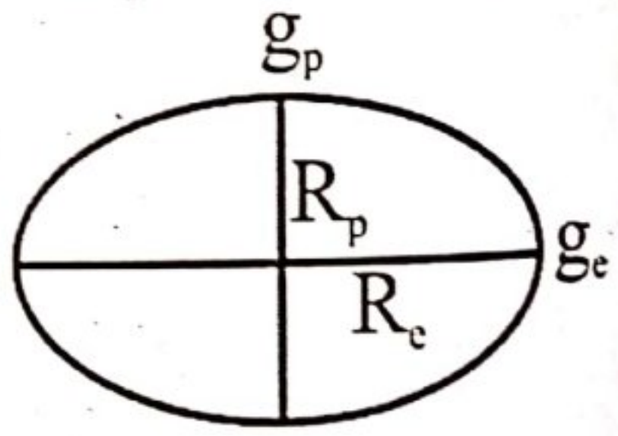
From equation (i) and (ii) $g' = g\left(\frac{R}{R+h}\right)^2 = g\frac{R^2}{r^2}$ $[\text{As } r = R+h]$

- As we go above the surface of the earth, the value of g decreases because $\mathbf{g' \propto \frac{1}{r^2}}$
- If $r = \infty$ then $g' = 0$, i.e., at infinite distance from the earth, the value of g becomes zero.
- If $h << R$, i.e., height is negligible in comparison to the radius then $\mathbf{g' = g\left[1 - \frac{2h}{R}\right]}$.

So as we go above the surface of earth value of g decreases.

- **Variation in g with depth:** $g' = g\left[1 - \frac{d}{R}\right]$ $\because$ d = depth so as we go below the surface of earth the value of g decreases.
- **Variation in g Due to Shape of Earth:** Earth is elliptical in shape. It is flattened at the poles and bulged out at the equator. The R_e radius is about 21 km longer than polar radius at equator

As at equator $\mathbf{g_e = \frac{GM}{R_e^2}}$.....(i) **and** at poles



$\mathbf{g_p = \frac{GM}{R_p^2}}$.....(ii)

- From (i) and (ii) $\frac{g_e}{g_p} = \frac{R_p^2}{R_e^2}$

Since $R_{equator} > R_{pole}$

and $g_{pole} > g_{equator}$

or $g_p = g_e + 0.018 ms^{-2}$

Therefore, the weight of body increases as it is taken from equator to the pole.

ARTIFICIAL SATELLITES

An object revolving around a planet is called satellite

- Moon is natural satellite of Earth
- Moon's orbital angular velocity and spin angular velocity are same
- A man made rocket or space ship revolving around the earth is called artificial satellite.
- Artificial satellite revolves around the earth due to force of gravity.

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- Critical velocity of an artificial satellite is $v = \sqrt{gR} = 7.9 \text{ km s}^{-1}$
- Period of such artificial satellite is 5060s or 84 min.

POINT 70 PONDER

Geostationary orbit is also called parking orbit.

Therefore, the weight of body increases as it is taken from equator to the pole.

REAL AND APPARENT WEIGHT

Force with which earth attracts a body towards its center is equal to the real weight of the body.
The force required to prevent a body from free fall is called its apparent weight.

- Real weight can never be zero while apparent weight may be equal to real weight or zero or greater than real weight or less than real weight.
- To observe weightlessness, the frame of reference of observer must be the same as that of satellite or should move like parallel to its fall. e.g. weightlessness is observed only by observer inside the lift not outside it.

POINT 70 PONDER

In a lift we only feel the difference in weights when the lift either start moving up or down, once constant velocity is achieved then weight variation become zero as well.

- Weight of object in a stationary or constantly moving lift is; $w' = mg$
- Weight of object in an elevator accelerating upward is; $w' = (g + a)m$
  Weight of object in an elevator accelerating downward is; $w' = (g-a)\, m$

ORBITAL VELOCITY

Orbital velocity for a satellite is $v = \sqrt{\frac{MG}{r}}$

where, $r = (R + h)$

This shows that mass of satellite is not important in describing its orbital velocity.

ARTIFICIAL GRAVITY

- Artificial gravity is created by setting satellite into rotation about its own axis.
- Artificial gravity is a reactional force, which gives impression of real gravity, when $a_c = g$.
- Frequency of rotation to produce artificial gravity, in a spaceship is;

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{R}}$$

- Time period of rotation to produce artificial gravity, equal of real gravity is;

$$T = 2\pi\sqrt{\frac{R}{g}}$$

GEO-STATIONARY & COMMUNICATION SATELLITES

A satellite whose position does not change w.r.t a certain point on earth is called geo-stationary satellite.

- Its orbital motion is synchronized with the rotation of earth.
- Geo-stationary satellite completes one rotation in **24 hours.**

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- Three geo-stationary satellites placed at 120° intervals about the equator can effectively cover the whole globe for communication.
- Radius of geo-stationary orbit is given by $r = \left(\frac{GMT^2}{4\pi^2}\right)^{1/3}$

  Its value is 4.23×10^4km from center of earth through the equator to the satellite.
- Height of geo-stationary satellite above the equator is **36000km.**
- **Kepler's Third Law:** The square of the orbital period of a planet is proportional to the cube of the mean distance from the Sun i.e. $T^2 \propto r^3$.
- The largest satellite communication system is managed by 126 countries and named as International Telecommunication Satellite Organization **(INTELSAT).**

NEWTON'S & EINSTEIN'S VIEWS OF GRAVITATION

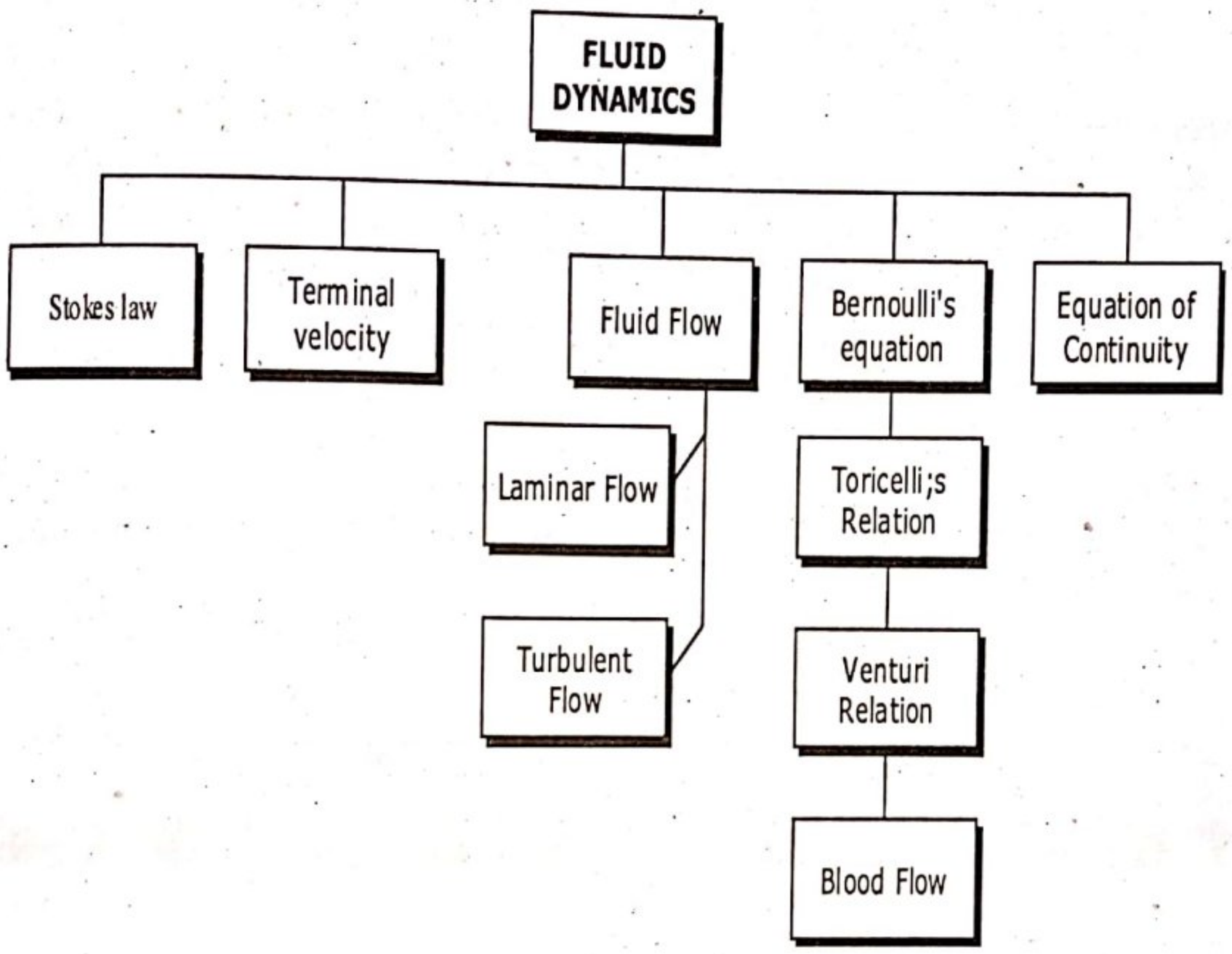
- According to Newton, gravitational interaction is taking place between material objects and is directly proportional to the product of the masses of the objects and inversely proportional to the square of the distance between their centre.
- According to Einstein, gravitational interaction is taking place between material objects and also between material object and electromagnetic radiation.
- According to Einstein, gravity follows the inverse square law, but when gravitational fields are very strong inverse square law does not hold.
- Einstein's theory is more close to the experimental facts than that of Newton's theory.

POINT TO PONDER

If the gravity and acceleration of light are precisely equal then gravity must bend light as measured in solar eclipse in 1919.

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6 CHAPTER FLUID DYNAMICS



Fluids

- Liquids and gases can flow and are thereby classified as fluids.
- The study of fluids at rest is called hydrostatics.
- Fluid dynamics deals with fluids in motion.

Density

- The density of a substance is defined as its mass per unit volume.

$$\text{Density}(\rho) = \frac{\text{Mass}(m)}{\text{Volume}(V)}$$

- In M.K. S. System the unit of density is kg m^{-3}.

PRESSURE

- Pressure at a point due to fluid is the normal force exerted by the fluid on unit area containing the point. $\text{Pressure}(P) = \frac{\text{Force}(F)}{\text{Area}(A)}$
- Pressure is a scalar quantity. Pressure acts normal to a surface and it is always compressive in nature, therefore, only its magnitude is required for its complete description.
- The S.I unit of pressure is N m^{-2} and is also called Pascal (Pa).
- The other common units of pressure are the atmospheric and bar.

1 atm = 1.013×10^5 Pa $\Rightarrow$ 1 bar = 10^5 Pa

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Thrust: The normal force exerted by a fluid on any surface in contact with it is called thrust.

Thrust = Pressure x Area

Pascal's law: The pressure exerted by a liquid at a point is the same in all directions. This principle is used in a hydraulic jack or a lift where a heavy load can be lifted up by a small force.

$$\frac{F_1}{F_2} = \frac{A_1}{A_2}$$

Archimedes principle: A body that is partially or entirely submerged in a fluid, feels an upward force equal in magnitude to the weight of the displaced fluid.

Buoyancy: **(i)** The upward thrust which any liquid or gas exerts upon a body partly or fully submerged in it, is called its buoyancy. **(ii)** The point at which the buoyancy of a liquid acts on a body is called the centre of buoyancy or the centre of floatation.

The magnitude of this upward buoyant force (B) is given by Archimedes principle.

i.e. $$B = V \rho g$$

Laws of floatation:

- When $w > w'$, i.e., the weight of the body is greater than the weight of the liquid displaced by it, the body sinks.
- When $w = w'$, i.e. when the weight of the body is equal to the weight of the liquid displaced by it, the body floats being wholly immersed anywhere in the liquid.

When $w < w'$, i.e., then the weight of the body is less than the weight of liquid displaced by it, the body floats on the surface of the liquid being partly immersed in the liquid.

VISCOUS DRAG FORCE AND STOKES LAW

- Viscosity is the measure of the force required to slide one layer of a liquid over another.
- SI unit of coefficient of viscosity is kg m^{-1} s^{-1} and dimension $ML^{-1}T^{-1}$
- Substance that flows easily like water etc has lesser coefficient of viscosity.
- The force experienced by an object while moving in a viscous medium is called drag force.
- The drag force in a medium depends on the profile of the object and velocity of the same object and nature of medium

Mathematically drag force can be related with above stated factors using Stoke's law

$$F_D = 6\pi \eta r v_t$$

The Stoke's law holds well at low speeds only for spherical bodies.

TERMINAL VELOCITY

When a spherical object falling gains a constant speed in a medium then the net force acting on it is zero and the corresponding speed is called as terminal velocity represented as v_t

$$v_t = \left(\frac{g}{6\pi\eta r}\right)m \text{ and } v_t = \left(\frac{2\rho g}{9\eta}\right)r^2$$

Where η is the coefficient of viscosity of the fluid.

POINT TO PONDER

When an object is moving in a fluid at considerably higher speed then the force of drag is no more proportional to the speed.

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FLUID FLOW

- In a fluid if every particle that passes a particular point, moves along exactly the same path as followed by particles which passed that point earlier then flow is called *streamline or laminar*
- Irregular or unsteady flow of the fluid is called *turbulent flow*

Characteristics of ideal fluid

(i) It is non viscous i.e. $\eta = 0$

(ii) It is incompressible $\rho = constt$

(iii) Its motion is steady

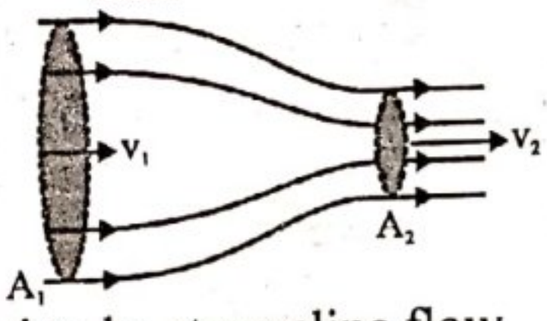
POINT TO PONDER

At higher velocities of fluid flow the flow is turbulent and in this condition the exact path of fluid particles cannot be predicted.

EQUATION OF CONTINUITY

This equation is obtained by using law of conservation of mass of flowing of ideal fluid, and is written as:

- $\rho_1 A_1 v_1 = \rho_2 A_2 v_2$ OR ρAv=constant $= \frac{\text{mass}}{\text{time}}$ = mass flow rate of fluid.
- $A_1 v_1 = A_2 v_2$ OR Av = Constant = $\frac{\text{volume}}{\text{time}}$ = volume flow rate of fluid.



The flow of ideal fluid is assumed to be streamline flow.

BERNOULLI'S EQUATION

Bernoulli`s equation is derived from conservation of mechanical energy.

- *Bernoulli`s equation is* $P + \frac{1}{2}\rho v^2 + \rho gh = constant$
- Fluid have three types of energies-

(i) Potential energy = mgh or potential energy per unit volume = ρgh

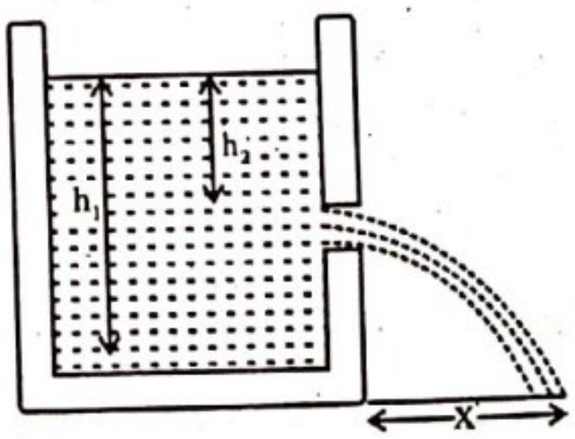
(ii) Kinetic energy = $\frac{1}{2}mv^2$ or kinetic energy per unit volume = $\frac{1}{2}\rho v^2$

(iii) Pressure energy = PV or pressure energy per unit volume = P

APPLICATIONS OF BERNOULLI'S EQUATION

Speed of Efflux

- Speed of efflux is determined by Torricelli`s theorem $v = \sqrt{2g(h_1 - h_2)}$ where $(h_1 - h_2)$ is height of fluid level from the orifice. This theorem explains streamline flow of ideal fluid under the action of gravity only.
- Speed of efflux depends upon the height through which fluid falls under the action of gravity
- Pressure of fluid increases if the speed of fluid decreases and vice versa, according to the relation $P + \frac{1}{2}\rho v^2 = constant$.



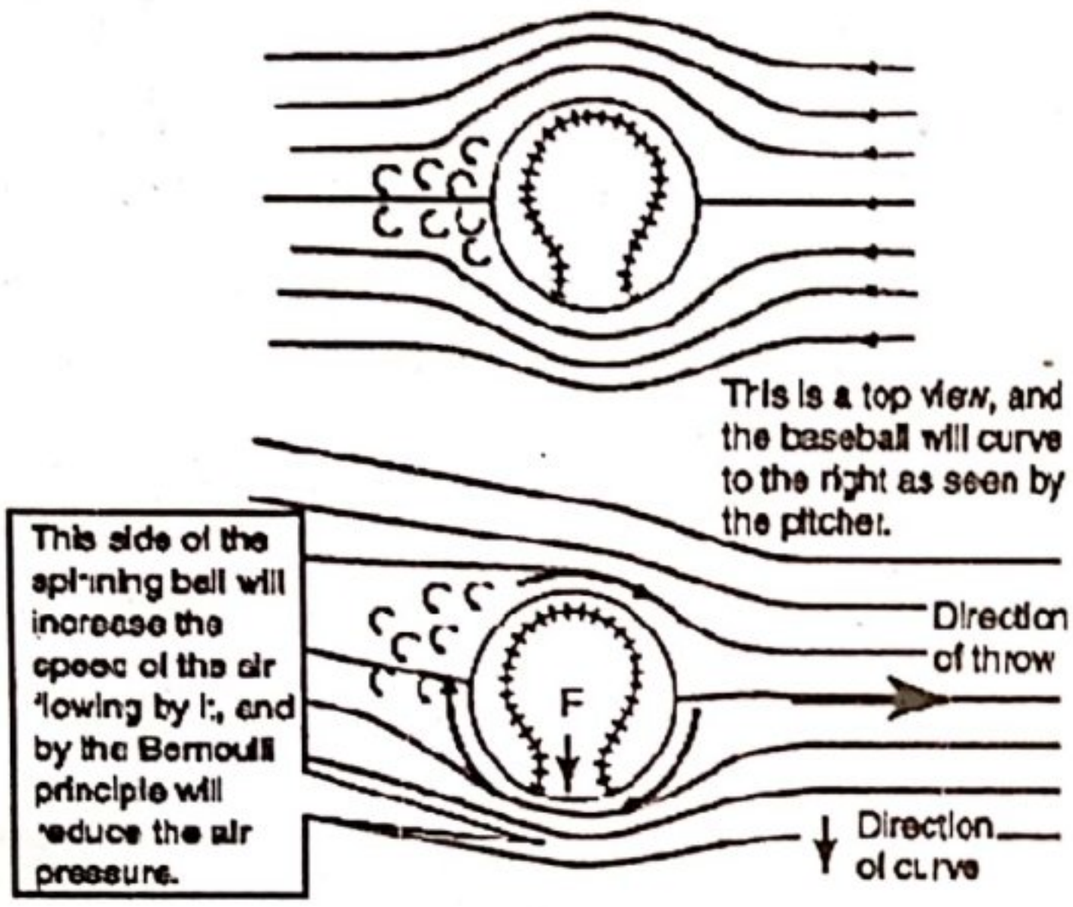
- An aero plane lifts due to the difference of pressure of air on its wings
- Swing in cricket and tennis ball is also due to difference of pressure on its two sides
- There is a danger that a person standing near a fast moving train to fall towards it.
- Venturimeter is a device used to measure the speed of liquid flow

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- Venturimeter works according to venturi relation which is $P_1 - P_2 = \frac{1}{2}\rho v_2^2$
- Mixing of petrol with air in carburetor is according to the Bernoulli`s principle.

POINT 70 PONDER

The cricket players usually polish one side of the ball and make rough other side of the ball to get the differential air pressure to swing a ball in air.



The roughness of the ball's surface and the laces on the ball are important! With a perfectly smooth ball you would not get enough interaction with the air.

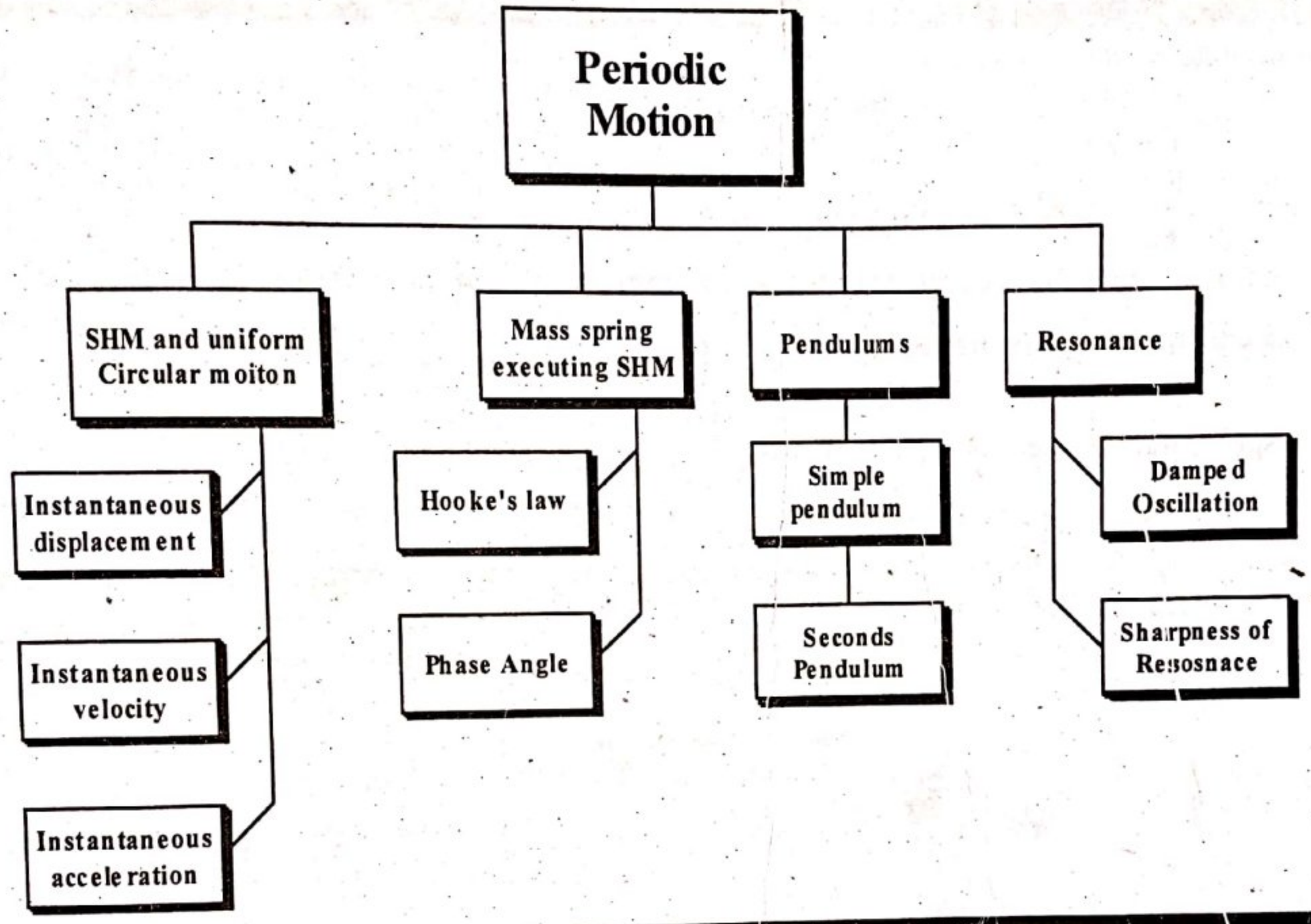
BLOOD PRESSURE

- Instrument used to measure blood pressure is called sphygmomanometer. It measures blood pressure dynamically.
- Blood pressure is measured in the unit of torr, 1 torr = 133.3 N m^{-2}=1mm of Hg
- For normal healthy person the systolic pressure is 120 torr and diastolic pressure is 75 to 80 torr.
- At systolic pressure the blood flow is turbulent while it switches from turbulent to laminar at diastolic pressure.

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CHAPTER 7

OSCILLATIONS



SIMPLE HARMONIC MOTION

- Vibratory motion is that in which a body moves to and fro about a fixed position along same path.

e.g.

(i) Motion of simple pendulum

(ii) Motion of molecules of a solid

- Simple harmonic motion (SHM) is a special type of vibratory motion in which;

(i) $\vec{a} \propto -\vec{x}$

(ii) $\vec{a}$ is directed towards mean position.

- Restoring force is always directed towards mean position hence assigned negative sign.
- Periodic motion is that which repeats itself after equal time intervals.
- Vibration is one complete round trip of a body about its mean position.
- Time period is defined as time taken by vibrating body to complete its one vibration and denoted by T.
- Frequency is number of vibrations per second and denoted by f so $f = \frac{1}{T}$

Its unit is Hz, other units are vibration/s, cycle/s, rev/sec

- Amplitude is maximum distance from mean position
- Angular frequency is $\omega = 2\pi/T \rightarrow \omega = 2\pi f$

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- Phase is the angle which specifies the displacement and direction of motion of the point executing SHM i.e phase = $\theta = \omega t$
- Initial angle at t = 0 is called phase constant and denoted by φ
- If phase constant $\phi = 90^0$, then displacement $x = x_0 \sin(\omega t + 90^0) = x_0 \cos \omega t$, and simple harmonic oscillator starts its SHM from positive extreme position.

A HORIZONTAL MASS-SPRING SYSTEM

- For spring, Hooke's law states that;

strain $\propto$ stress (within elastic limits)

$$F = k\,x$$

Where $k = \frac{F}{x}$ is called spring constant or force constant.

If a spring is cut into two equal parts then spring constant of each spring is doubled.

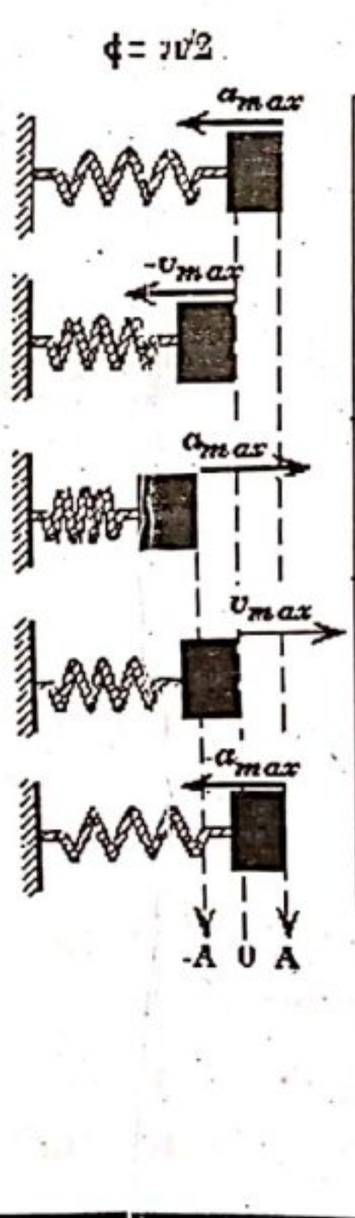
- Mass attached to spring has SHM. $\vec{a} = -\frac{k}{m}\vec{x}$

For spring mass system doing SHM $\omega = \sqrt{\frac{k}{m}}$

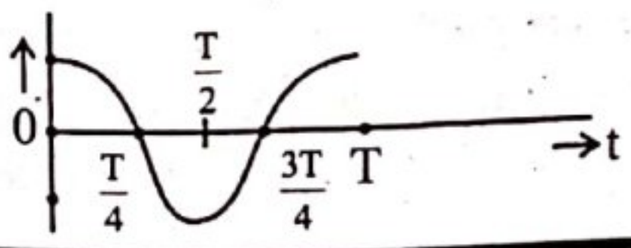
$$\vec{a} \propto -\vec{x}$$

- Mass-spring system has S.H.M and we can trace its waveform (pictorial display between time and displacement for S.H.M) by following relation;

$$x = x_o \sin\left[\frac{2\pi}{T}\right]t$$



Time t	Position $x(t)$	Velocity $v(t)$	Accel. $a(t)$	KE	PE
0	x_{max}	0	$-a_{max}$	0	PE_{max}
$\frac{T}{4}$	0	$-v_{max}$	0	KE_{max}	0
$\frac{T}{2}$	$-x_{max}$	0	a_{max}	0	PE_{max}
$\frac{3T}{4}$	0	v_{max}	0	KE_{max}	0
T	x_{max}	0	$-a_{max}$	0	PE_{max}



COMBINATIONS OF SPRING

Spring in Series

The resultant of spring constant in case of the series combination is

$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} + \ldots\ldots\ldots\ldots\ldots$$

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Spring in Parallel

The resultant of spring constant in case of the parallel combination is

$$k = k_1 + k_2 + \ldots\ldots\ldots\ldots$$

This behaviour of springs resembles with capacitances in series and in parallel combinations.

HORIZONTAL MASS SPRING SYSTEM

- *Time period* of single mass attached to spring is given as; $T = 2\pi\sqrt{\frac{m}{k}}$

$T \propto \sqrt{m}$ $\quad$ $T \propto \frac{1}{\sqrt{k}}$

Its displacement is given as; $x = x_0 \sin \omega t$

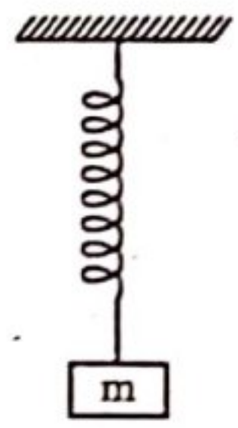
- *Instantaneous velocity* of mass 'm' attached to a spring is given as;

$$v_{ins} = \sqrt{\frac{k}{m}\left(x_o^2 - x^2\right)} = \sqrt{\frac{k}{m}}\, x_o \sqrt{1 - \frac{x^2}{x_0^2}} = v_{max}\sqrt{1 - \frac{x^2}{x_o^2}}$$

- *Maximum speed* of mass attached to spring is given as;

$$v_{max} = v_o = x_o\sqrt{\frac{k}{m}}$$

- Instantaneous velocity of spring – mass system doing SHM is proportional to constant of proportionality being the maximum velocity. $\sqrt{1 - \frac{x^2}{x_o^2}}$



- **In case of vertical spring $F = mg = kx$**

$\therefore$ $\quad \frac{m}{k} = \frac{x}{g}$ (Here x is elongation)

- Then time period $\quad T = 2\pi\sqrt{\frac{x}{g}}$

Velocity	At mean position max	At extreme position zero
Acceleration	At mean position is minimum	At extreme positions is maximum

POINT TO PONDER

In a one complete vibration a body covers a distance equal to four times of the amplitude.

MOTION OF PROJECTION OF A BODY MOVING IN A CIRCLE ON DIAMETER

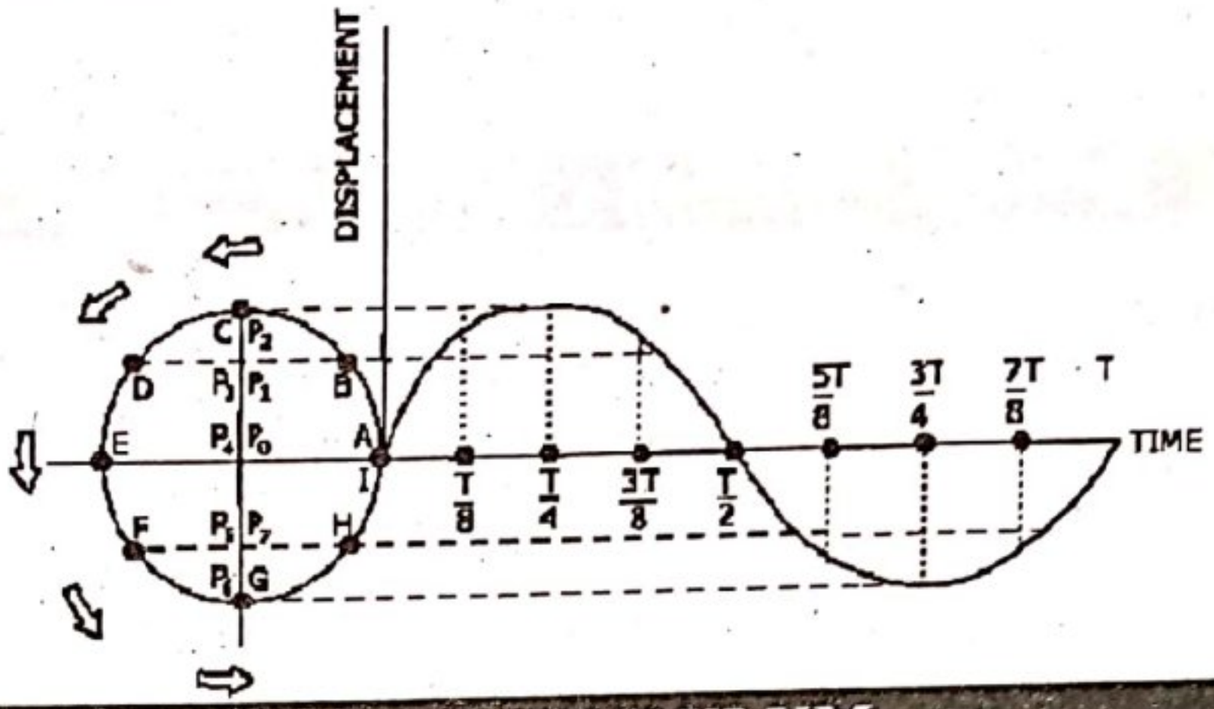
- Motion of projection of a body moving in a circle, on the diameter with constant speed is S.H.M
- Its acceleration is given as; $a = -\omega^2 x$
- Time period of projection is given as; $T = \frac{2\pi}{\omega}$
- Speed of projection is given as;

$v = \omega\sqrt{r^2 - x^2}$ where r = radius of the circle = amplitude of S.H.M

- Projection speeds up when moving towards the centre of circle.
- Projection slows down when moving away from the centre of circle.

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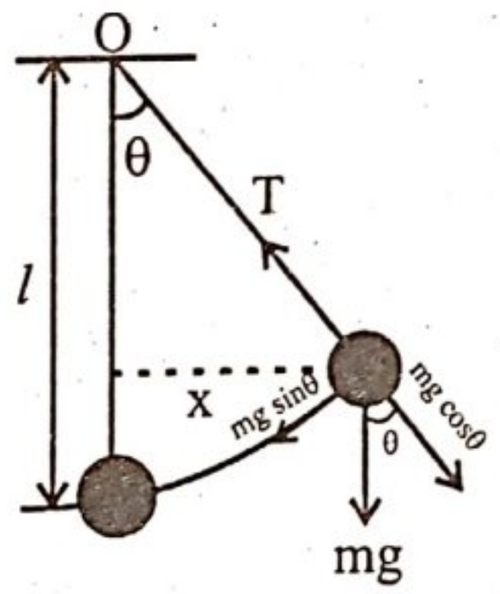
- If speed ω of body in circular motion is not constant then projection does not have S.H.M but has vibratory motion, which is non-S.H.M.



SIMPLE PENDULUM

It consists of a heavy point mass suspended from a rigid support by means of almost weightless and inextensible string.

- *Galileo invented simple pendulum.*
- Motion of simple pendulum is S.H.M if there is no damping.
- Damping force reduces the amplitude of simple pendulum continuously and finally its motion is stopped.



- In absence of damping force, *restoring force* on simple pendulum is given as;

  $F_r = -mg \sin\theta$, and for small amplitude oscillations $F_r = -mg\theta$.

- Equation of *acceleration* of simple pendulum for small amplitude is;

$$a = -\left(\frac{g}{l}\right)x$$

Thus $\omega = \sqrt{\frac{g}{l}}$ for simple pendulum and does not depend on mass like the mass-spring system does.

- *Time period and frequency* of simple pendulum are given as;

$$T = 2\pi\sqrt{\frac{l}{g}} \text{ and } f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$$

- If amplitude of simple pendulum is not small then, it has non-S.H.M as $a = -g \sin\theta$ and we know that $\sin\theta = \theta$ only when θ is small.
  - **Pendulum Suspended in a Lift:** If the pendulum is suspended in a lift ascending up with uniform acceleration 'a' then its time-period is $T = 2\pi\sqrt{\frac{l}{g+a}}$

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- If the pendulum is suspended in a lift descending down with acceleration 'a' then

$$T = 2\pi\sqrt{\frac{l}{g-a}}$$

POINT TO PONDER

The time period of simple pendulum is independent of its mass and its amplitude.

Kinds of pendulum

(a) simple pendulum

(b) compound pendulum or physical pendulum

(c) torsion pendulum

- A second pendulum has following characteristics:

Time period	2 seconds
Frequency	0.5 Hz
Length	0.99 or 1 meter

ENERGY CONSERVATION IN SHM

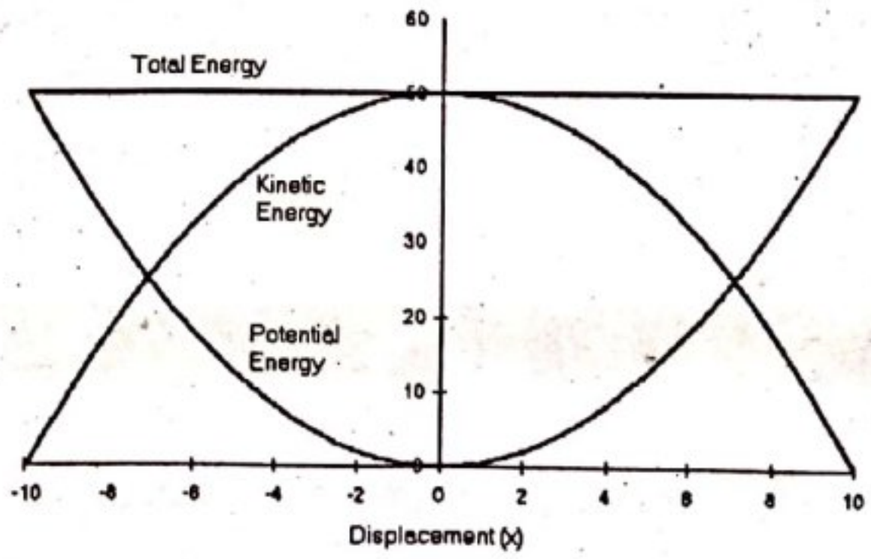
- Its K.E is given as;

$$K.E_{inst} = \frac{1}{2} k x_o^2 \left(1 - \frac{x^2}{x_o^2}\right)$$

$$(K.E)_{max} = \frac{1}{2} k x_o^2$$ It is at mean position.

$$(K.E)_{min} = 0$$ It is at extreme position.

$$K.E_{inst} = (K.E)_{max}\left(1 - \frac{x^2}{x_o^2}\right)$$



- Its P.E is given as;

$$P.E_{inst} = \frac{1}{2} k x^2$$

$$(P.E)_{max} = \frac{1}{2} k x_o^2$$

It is at extreme position.

$(P.E)_{min} = 0$

It is at mean position.

- Total energy of system $= \frac{1}{2} k x_o^2$ energy remain conserve in SHM. In one vibration K.E. attains its maximum value twice.

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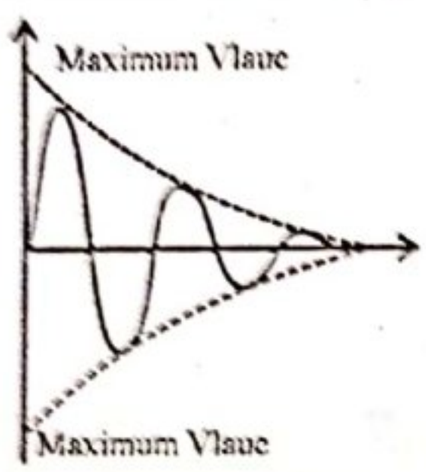
FREE & FORCED OSCILLATIONS

- Oscillation of a system is called free *vibration* if it oscillates without the interference of an external force.
- Frequency of free oscillation is called *natural frequency of the system*
- When a system performs oscillation in the presence of external periodic force its vibration is called *forced oscillation*.
- A physical system under going forced vibration is known as driven harmonic oscillator.

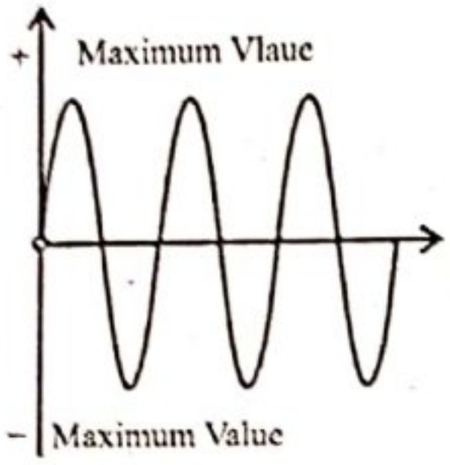
DAMPED OSCILLATION

Such oscillations in which the amplitude decreases steadily with time are called as damped oscillations.

- In shock absorber of a car critical damping is applied.

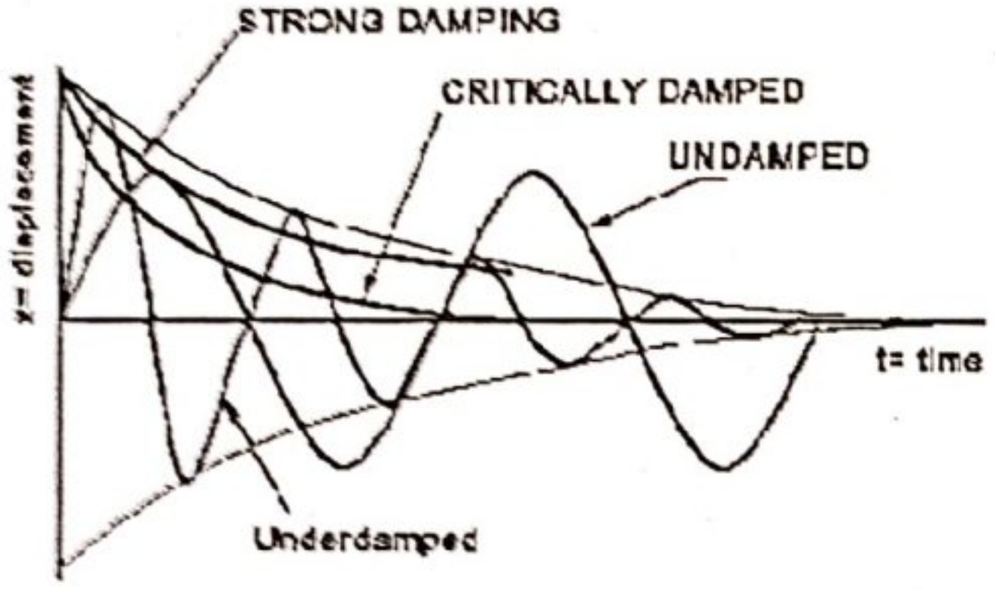


(a) Damped Oscillations



(b) Undamped or Sustained Oscillations

- **For Information**



RESONANCE

Phenomenon of increase in amplitude of a body (capable of vibrating) under the action of a periodic force whose time period is equal to natural time period of body.

OR

Specific response of a system to external periodic force whose time period is equal to natural time period of a body.

OR

Process in which one body transfers its vibrations to nearby body whose natural time period is agreeable to it.

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POINT TO PONDER

Damping is a process whereby energy is dissipated from the oscillating system.

- For tuning circuit of T.V or radio or mobile phone, electrical resonance takes place at following frequency;

$$f = \frac{1}{2\pi\sqrt{LC}}$$

- Magnetic resonance imaging is a resonance phenomenon using radio frequency waves. Magnetic field. It is less damaging than X-rays imaging process.
- Suspension bridge may break down due to vibration with increased amplitude caused by resonance.
- We get tired on walking briskly because of forced oscillations fed into our legs for resonance.
- Loose parts of car produce noise at specific speed due to resonance.

SHARPNERS OF RESONANCE

- Amplitude of vibration decreases with damping force.
- Amplitude of vibration remain constant with undamped force
- Smaller the damped force, sharper is the resonance and vice – versa.

POINT TO PONDER

A microwave oven generates high frequency waves, which heat up water and fat molecules by large energy absorption, and hence food is cooked.

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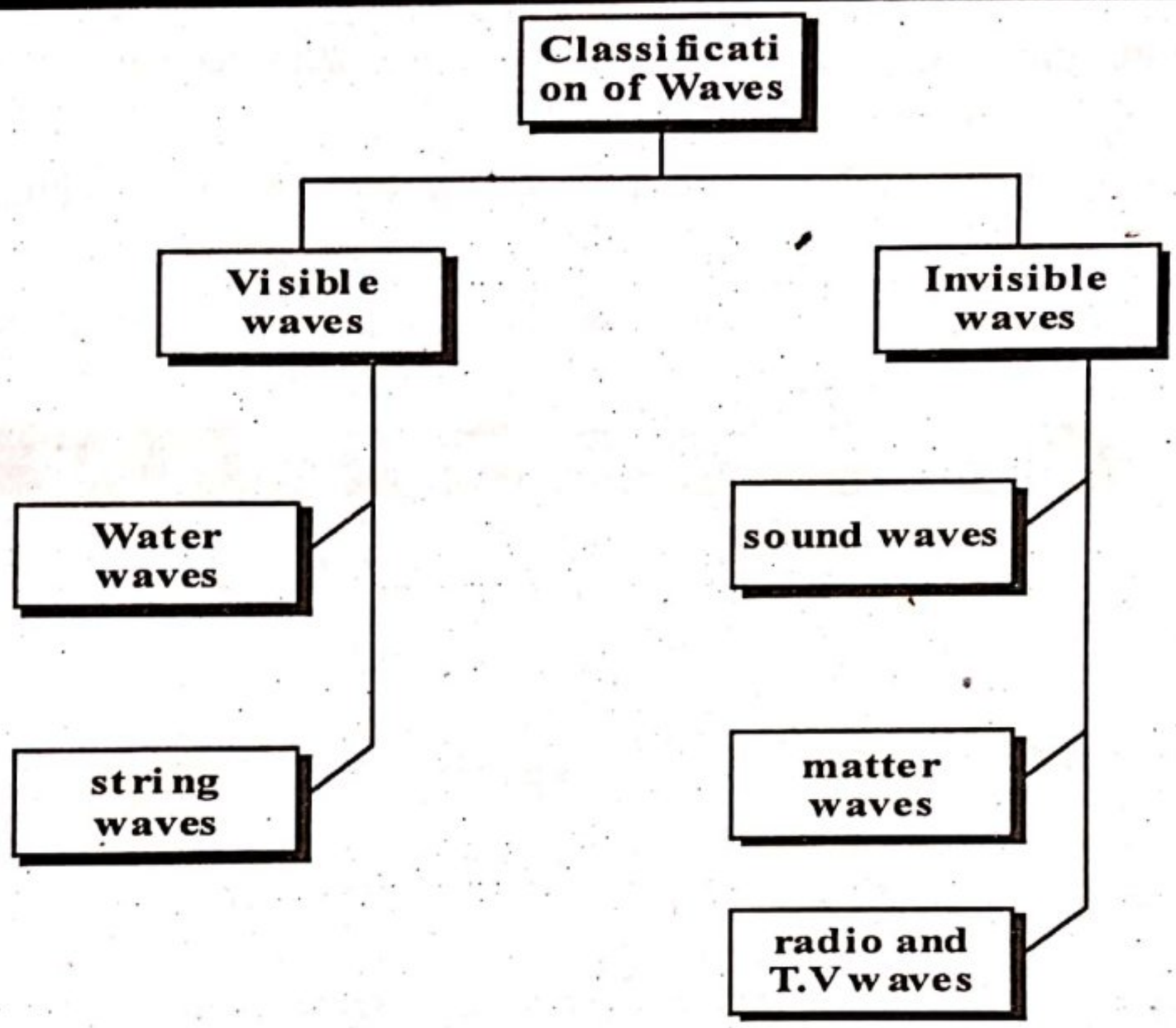
CHAPTER 8

WAVES

INTRODUCTION

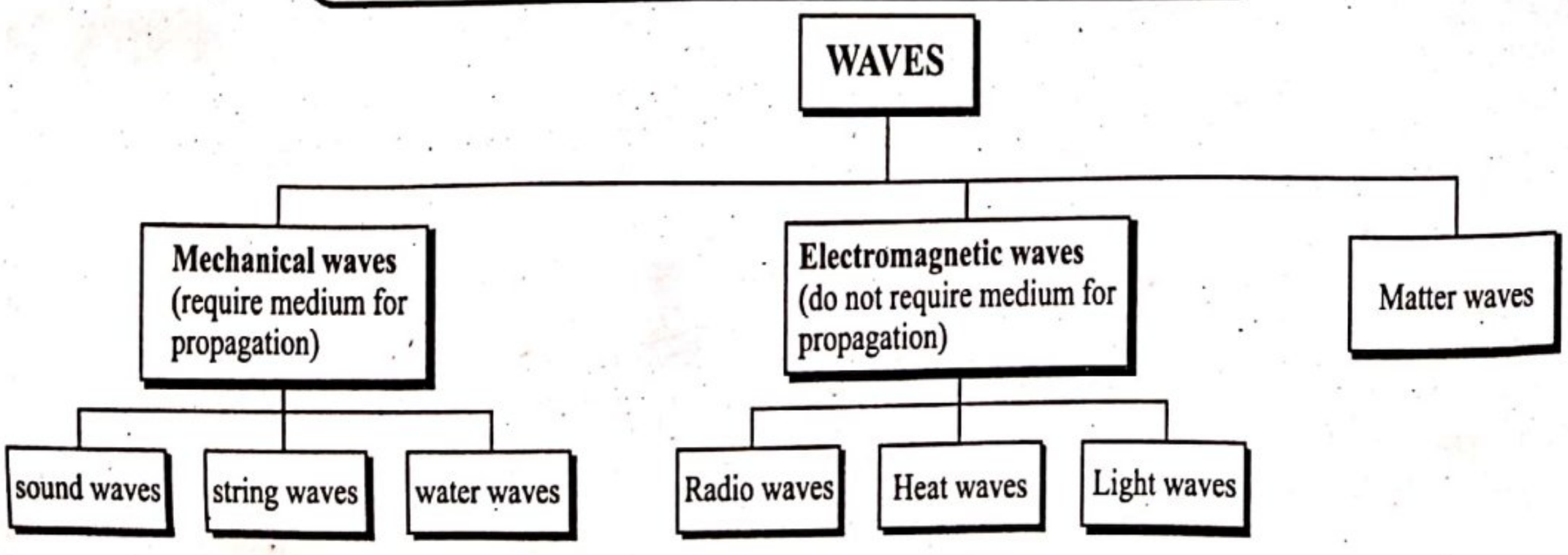
- Wave is due to disturbance created in a medium.
- Waves transport energy without transporting matter.

CLASSIFICATION OF WAVES



POINT TO PONDER

In case of mechanical waves we deal with the cooperative motion of a collection of particles.



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PROGRESSIVE/TRAVELING WAVES

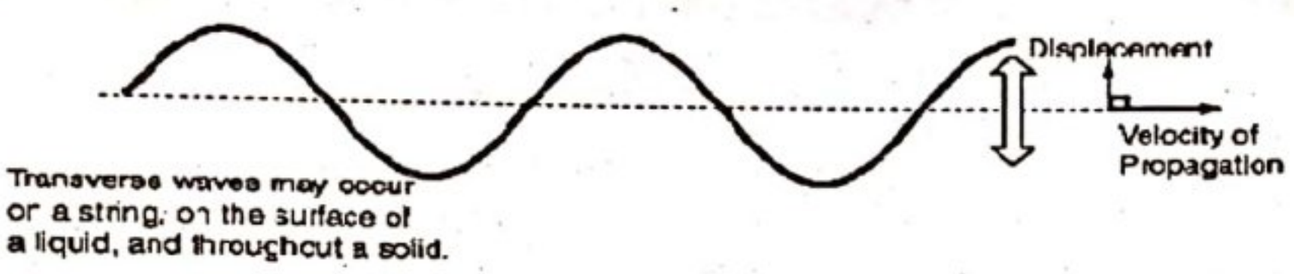
- Traveling wave is that which propagates or distributes its pulses in space along specific direction. e.g.

(i) Waves on a string
(ii) Waves on a water surface

PERIODIC WAVES

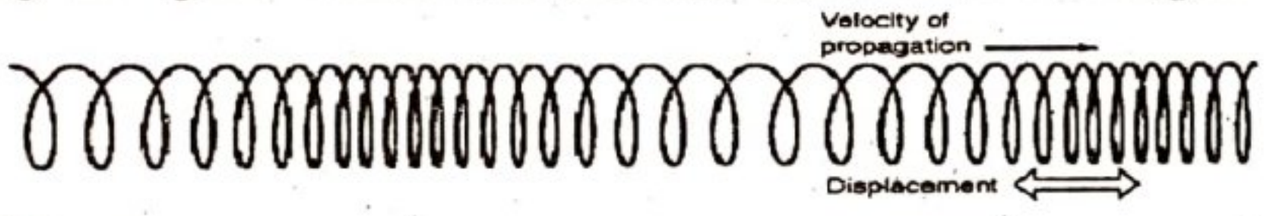
Periodic waves are those, which are repeated in regular interval of time.

- Periodic wave may be transverse or longitudinal.
- For transverse waves the displacement of the medium is perpendicular to the direction of propagation of the wave. A ripple in a pond and a wave on a string are easily visualized as transverse waves.



Transverse waves cannot propagate in a gas or a liquid because there is no mechanism for driving motion perpendicular to the propagation of the wave. In fluids, transverse waves die out very quickly and usually cannot be produced at all.

In longitudinal waves the displacement of the medium is parallel to the propagation of the wave. A wave in a "spring" is a good visualization. Sound waves in air are longitudinal waves.



Transverse Periodic Wave

- In a time interval equal to time period, a particle in the wave travels a distance equal to **wavelength.**
- For all waves $v=f\lambda$
- The particles in the wave separated by a distance which is integral multiple of λ i.e. $n\lambda$ are in phase with each other.
- The particles separated by a distance which is odd multiple of λ i.e: $\left(n+\frac{1}{2}\right)\lambda$ are **out of phase** to each other.

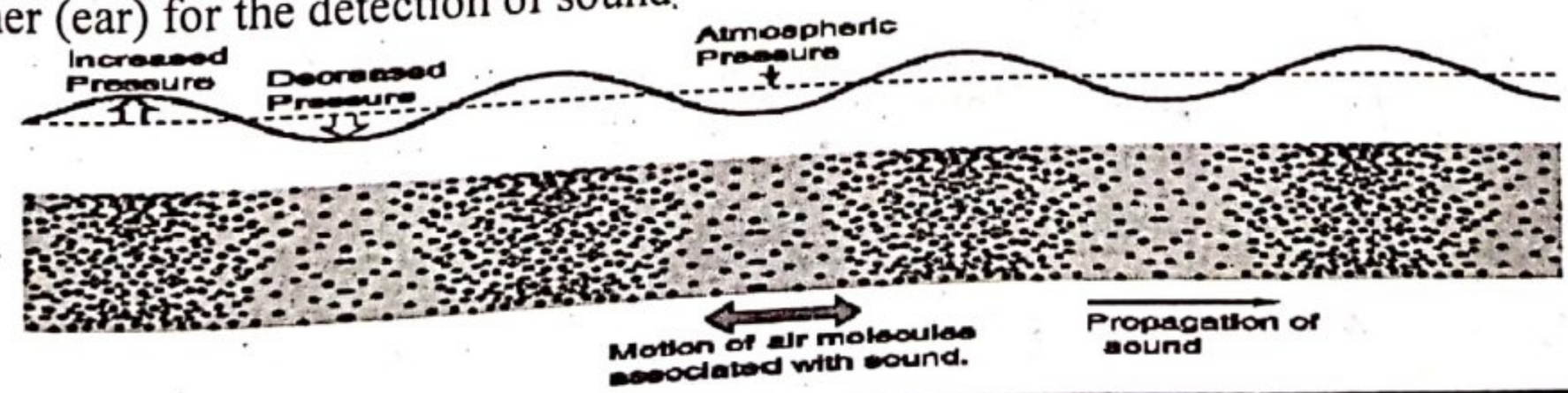
POINT TO PONDER

The waves transport both energy and momentum in a medium.

SOUND

- A vibrating body produces sound waves ($\lambda \approx 1m$).
- Three things are essential for sound.

(i) Vibrating body for production of sound
(ii) Medium for propagation of sound
(iii) Listener (ear) for the detection of sound.



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- Sound waves are longitudinal waves having three dimensional propagation in air.
- Longitudinal sound waves consist of compressions and rarefactions.
- Compression is a region where crowding of particles of medium is maximum.

WAVE	SPEED (m/s)
EM waves	300 000 000
Sound in air	340
Sound in water	1500
Sound in steel	5000

- Rarefaction is region where crowding of particles of medium is minimum.
- Sound waves produce Reflection, Refraction, Diffraction, Interference but not polarization because sound waves are longitudinal.

VELOCITY OF SOUND IN AIR

- Speed of any mechanical wave is found by the following formula

$$v = \sqrt{\frac{E}{\rho}}$$ where E = modulus of elasticity of medium, ρ=density of medium

- In gases, sound travels in the form of compressional wave; and gases have bulk modulus of elasticity. So for gases, we get-

$$v = \sqrt{\frac{E_{bulk}}{\rho}}$$

- Bulk modulus of elasticity is ratio of stress to volumetric strain

$$E_{bulk} = \frac{\Delta P}{\left(\frac{\Delta V}{V}\right)}$$

- Newton proved that for air **the isothermal modulus of elasticity is** $E_{bulk}=P$, and speed of sound is

$$v = \sqrt{\frac{P}{\rho}}$$

- At S.T.P the speed of sound in air is

$$v = \sqrt{\frac{hdg}{\rho}} \quad \text{(where d = density of mercury)}$$

$$v = \sqrt{\frac{76\times13.6\times981}{0.001293}}$$

$$= 28100 \text{ cm/s}$$

$$= 281 \text{ m/s}$$

Whereas experimental value is 332 ms^{-1}.

- Percentage error in Newton's calculation was 16% because of assumption that sound propagate through air isothermally.
- Laplace corrected Newton's formula by proposing that "sound wave does not propagates in air isothermally but adiabatically."
- Laplace's formula is given as;

$$v = \sqrt{\frac{\gamma P}{\rho}}$$ where $\gamma P = E_{\text{bulk modulus}}$ =adiabatic elastic modulus of fluid.

$$\gamma = \frac{C_p}{C_v} = 1.42 \text{ (for air)}$$

- Experimentally it is found that speed of sound increases by 0.61 ms^{-1} or 61 cms^{-1} for each 1°C rise in temperature.

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Effect of Moisture

Water vapours are lighter than air, thus the presence of moisture in air reduces density and hence the speed of sound increases in such cases.

Dependence of Velocity of Sound

(i) v is independent of pressure

(ii) $v \propto \frac{1}{\sqrt{\rho}}$

(iii) $v \propto \sqrt{T}$

(iv) $\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$

(v) $v_t = v_o + 0.61t$

POINT TO PONDER

The speed of sound in hydrogen is four times more than the speed of sound in oxygen at same temperature

PRINCIPLE OF SUPERPOSITION

When two or more waves reach a point of the medium simultaneously then the resultant displacement at that point of the medium is equal to sum of the individual displacements produced by each wave. This is called principle of superposition

$$Y_{total} = Y_1 + Y_2 + Y_3 + \ldots\ldots\ldots + Y_n$$

Applications

Interference

It is produced by superposition of two waves of same frequencies, which are traveling in the same direction.

Beats

These are produced by two waves of slightly different frequencies traveling in the same direction

Stationary Waves

These are produced by two waves of equal frequency and equal amplitude traveling along same line in opposite direction.

INTERFERENCE OF SOUND

Superposition (mixing up) of two identical sound waves while passing through same medium propagating along same direction is called their interference.

Conditions for interference

(i) coherent waves
(ii) same medium
(iii) same direction
(iv) identical waves
(v) Sources of sound should be close to each other

- In constructive interference, two interfering sound waves reinforce each other, so that the resultant is a louder sound.

Condition for Constructive Interference

Path difference = $n\lambda$ where $n = 0, \pm 1, \pm 2, \ldots\ldots\ldots$

- In destructive interference, two interfering sound cancel each other's effect, so that the resultant loudness of sound wave is become fainter.

Condition for Destructive Interference

Path difference = $\left(n + \frac{1}{2}\right)\lambda$ where $n = 0, \pm 1, \pm 2, \ldots\ldots\ldots$

- Echoing zone is region of constructive interference
- Silence zone is region of destructive interference
- Path difference is the difference between lengths of paths traveled by two waves in reaching the same point.

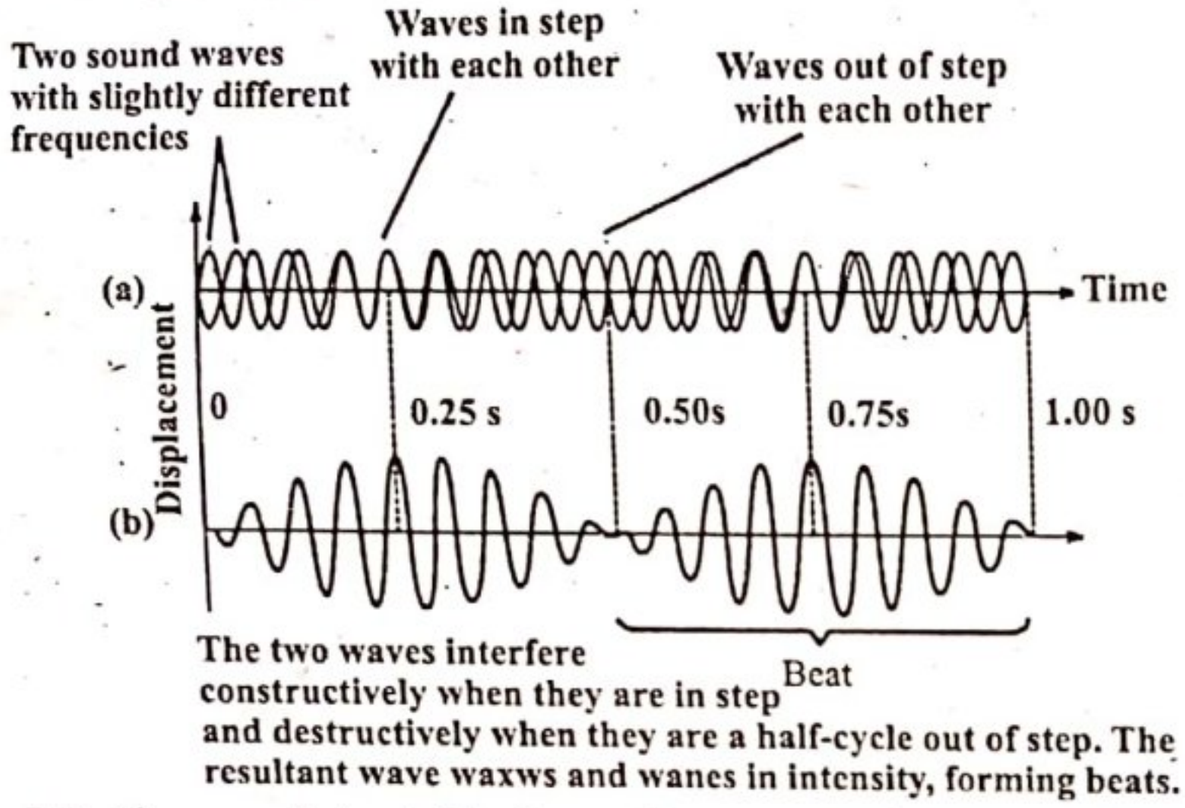
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BEATS

The periodic alterations of sound between maximum and minimum loudness are called beats.

- Beats are produced by the super position of two waves having slightly different frequencies travelling in same medium along same direction.
- Beat frequency is defined as number of beats per second.
- Absolute difference between frequencies of producing beats is equal to beat frequency

$$f_{beat} = |f_A - f_B|$$



The two waves interfere constructively when they are in step and destructively when they are a half-cycle out of step. The resultant wave waxws and wanes in intensity, forming beats.

POINT TO PONDER

If frequency of a tuning fork is 32 Hz then after 3/4 sec, it will complete 24 vibrations.

Maximum detectable beat frequency for normal human ear is 10Hz.

- Beats are used to:
  1- Determine unknown frequencies
  2- Tune musical instruments

REFLECTION OF WAVES

- All kinds of wave shows reflection
- When reflection of wave takes place from denser boundary, the phase of waves reverses. In this case, reflection co-efficient is maximum and transmission co-efficient is almost zero except for quantum mechanical transmission of particle from potential barrier.

POINT TO PONDER

The reflected wave has the same wavelength and frequency but its phase may change depending on the nature of reflecting medium.

- When reflection takes place from rarer boundary, there is no phase reversal. In this case, reflection co-efficient and transmission coefficient have considerable values.

TRANSMISSION OF WAVES

- Practically amplitude of transmitted wave is less than that of incident wave because some of energy of incident wave is wasted at point of discontinuity.
- Frequency of transmitted wave is same as that of incident wave but its velocity depends on density of medium as given below;

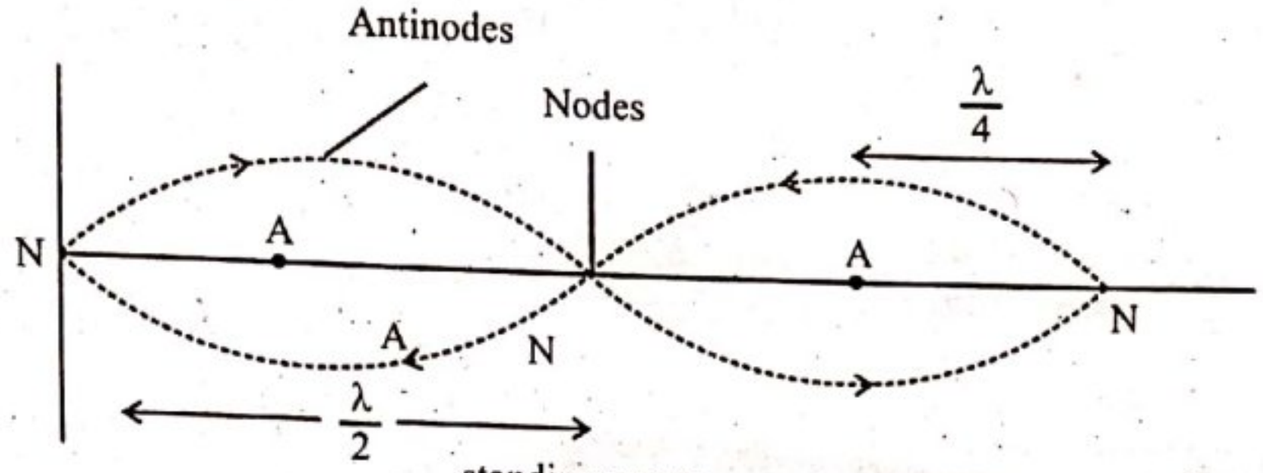
$$v \propto \frac{1}{\sqrt{\rho}}$$

- Since velocity of transmitted wave is different from original wave, therefore, wave length (λ) changes as frequencies of both waves are equal.

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STANDING WAVES

- Super position of two identical waves traveling opposite to each other in the same medium simultaneously, gives rise to stationary or standing waves
- Both constructive and destructive interference takes place in the formation of stationary waves.
- Points of constructive interference are called antinodes while points of destructive interference are called nodes as shown



standing waves

- Amplitude is maximum at antinodes and minimum (zero) at nodes.
- Nodes are stationary points whereas antinodes are points that vibrate with maximum amplitude.
- Two consecutive nodes or antinodes are separated by distance equal to $\lambda/2$ and an antinode and its consecutive node by $\lambda/4$.

POINT TO PONDER

The energy stored in anti-nodes at their extreme position is wholly potential while at equilibrium position the energy stored is wholly kinetic but total energy remains the same.

STANDING WAVES IN STRECTHED STRING

- At fixed end of string always node is formed while at free end of string always antinode is formed.
- If string is fixed at both ends, then number of nodes is one greater than no. of antinodes. **N = A+1**
- If string is free at one end, then number of antinodes is equal to that of nodes. **A = N**
- Speed of string wave is

$$v = \sqrt{\frac{T}{m}} = \sqrt{\frac{F}{m}}$$

m is called linear mass density.

POINT TO PONDER

The speed of stationary waves is independent of the No. of loops.

- Only the following quantized frequencies of transverse stationary waves on stretched string can be produced.

$$f_n = n\, f_1, \qquad n = 1, 2, 3, \ldots\ldots\ldots\ldots$$

where $$f_1 = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

f_1 is the lowest frequency (fundamental or basic frequency) at which first stationary wave is formed.

All other frequencies (f_2, f_3,…,f_n) which are integral multiple of fundamental frequencies are called overtones or harmonics.

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STANDING WAVES IN AIR COLUMNS

Standing waves in pipes

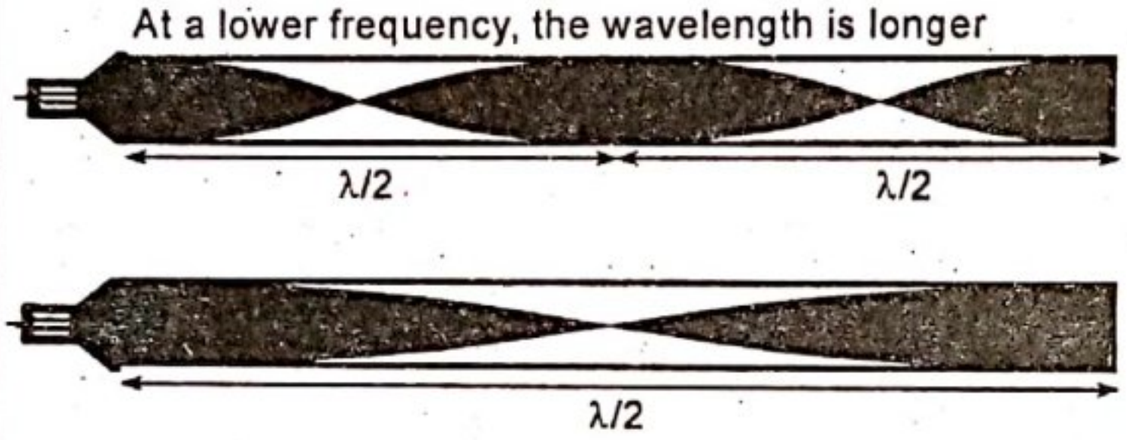
Closed pipes



loudspeaker

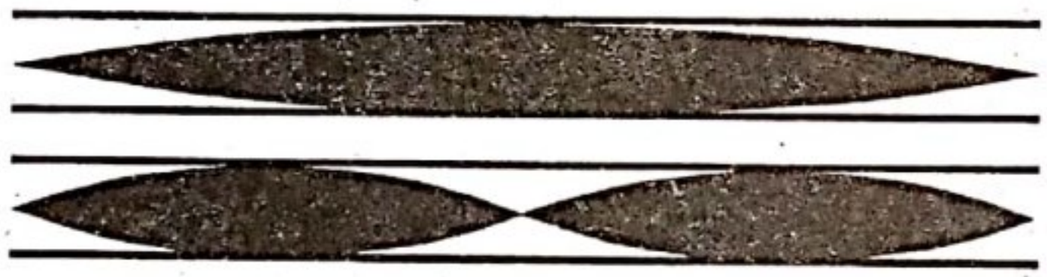
A loudspeaker sends a sound into a long tube. Dust in the tube can show nodes and antinodes. Nodes are half a wavelength apart. So are antinodes. Maximum amplitude shows maximum pressure variation and minimum motion of air (pressure antinode). Minimum amplitude shows minimum pressure variation and maximum motion of air (pressure node).

At a lower frequency, the wavelength is longer



The fundamental: The lowest frequency which can form a standing wave has wavelength equal to twice the length of the tube

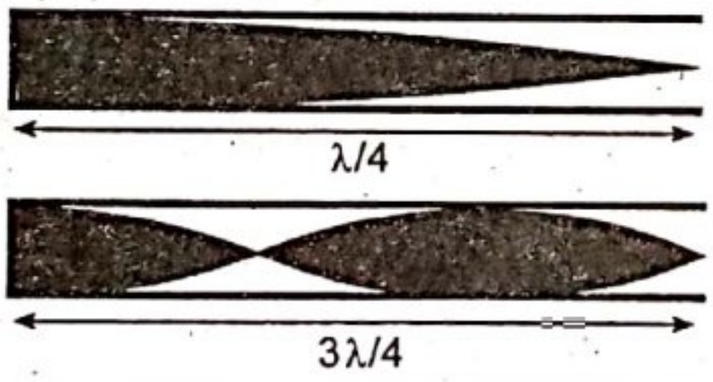
Pipes open at both ends



Sound can be reflected from an open end as well as from a closed end.

This is how open organ pipes and flutes work.

Pipes closed at one end



Pipes closed at one end are shorter, for the same note.

A clarinet is like this. An oboe is too, but with a tapered tube.

Some organ pipes are stopped at one end.

Frequencies of standing waves

	Pipes open or closed at both ends strings fixed at both ends	Pipes open at one end
Length L	$L = n\lambda$	$L = (2n-1)\lambda/4$
Fundamental	$f = v/2L$	$f = v/4L$
harmonics	2f	3f
	3f	5f
	nf	$(2n-1)f$

where n = 1,2,3.....

- Fundamental frequency of open pipe = 2 × fundamental frequency of closed pipe
- No. of harmonics in open pipe = 2 × No. of harmonics in closed pipe

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POINT TO PONDER

The open end of the organ pipe behaves as antinode while the closed end behaves as node in case of stationary waves through organ pipe. Why.

DOPPLER'S EFFECT

Apparent change in pitch (frequency) of sound is due to relative motion of source and observer.

- Doppler's effect was discovered by Doppler, an Australian physicist, in 1845.
- Apparent frequency of sound heard by **stationary listener** due to source **moving towards** him at speed 'u_s' is given as;

$$f' = \left(\frac{v}{v - u_s}\right) f \qquad f' > f$$

- Apparent frequency of sound heard by **stationary listener** due to source **moving away** from him at speed 'u_s' is given as;

$$f' = \left(\frac{v}{v + u_s}\right) f \qquad f' < f$$

- Apparent frequency of sound heard by a **person moving towards** a **stationary source with** speed 'u_0' is given as;

$$f' = \left(\frac{v + u_o}{v}\right) f \qquad f' > f$$

- Apparent frequency of sound heard by a listener **moving away from a stationary source with** speed 'u_0' is given as;

$$f' = \left(\frac{v - u_o}{v}\right) f \qquad f' < f$$

- When source and listener **move towards each other,** then frequency of sound heard by listener is given as;

$$f' = \left(\frac{v + u_o}{v - u_s}\right) f$$

Where v = true speed of sound u_o = speed of listener u_s = speed of source

- When source and observer are **moving away from each other,** then frequency of sound heard by listener is given as;

$$f' = \left(\frac{v - u_o}{v + u_s}\right) f$$

- Light observes Doppler's effect too.

Applications of Doppler's Effect

(i) Ships and submarine (sonar devices)
(ii) Bats (for traveling)
(iii) Radar (for detection)
(iv) Determining velocity of a star w.r.t earth
(v) to monitor blood flow in major arteries.

- When a star is moving away from Earth then wavelength of light increases and red shift of spectrum is observed
- When a star is moving towards the Earth then wavelength of light decreases and blue shift of spectrum is observed.

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9 CHAPTER PHYSICAL OPTICS

WAVE FRONT AND RAYS

- Wave front is a locus of points which have same phase of vibrations.
- Following are the types of wave front;

Spherical Wave Front

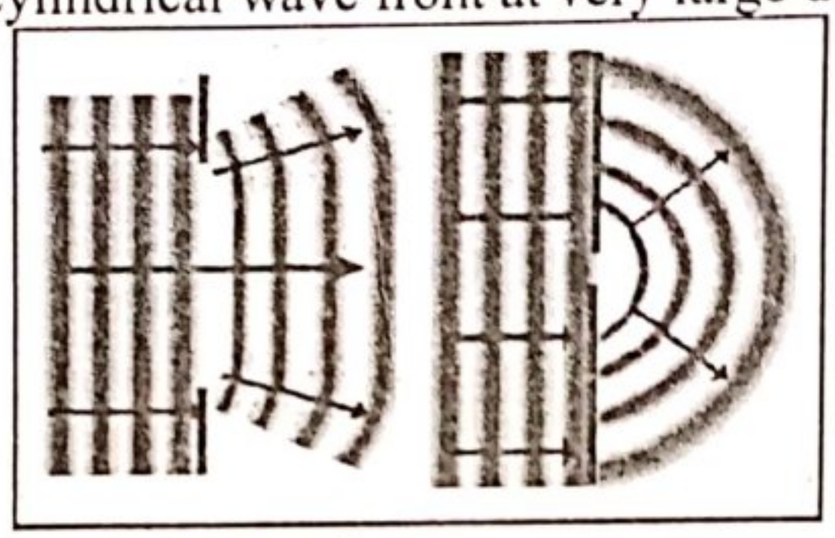
Set of points, which determine the surface of sphere.

Cylindrical Wave Front

Set of points, which determine the surface of cylinder.

Plane Wave Front

A small part of spherical or cylindrical wave front at very large distance from source of light



- Point light sources produce spherical wave fronts.
- When a point source is placed at focus of converging lens, plane wave fronts are obtained in laboratory.
- Plane wave fronts reach from the Sun to the Earth, as the earth is far off from the sun.
- The distance between two consecutive wave fronts is one wavelength.
- A line normal to the wave front including the direction of motion is called a ray of light.

POINT TO PONDER

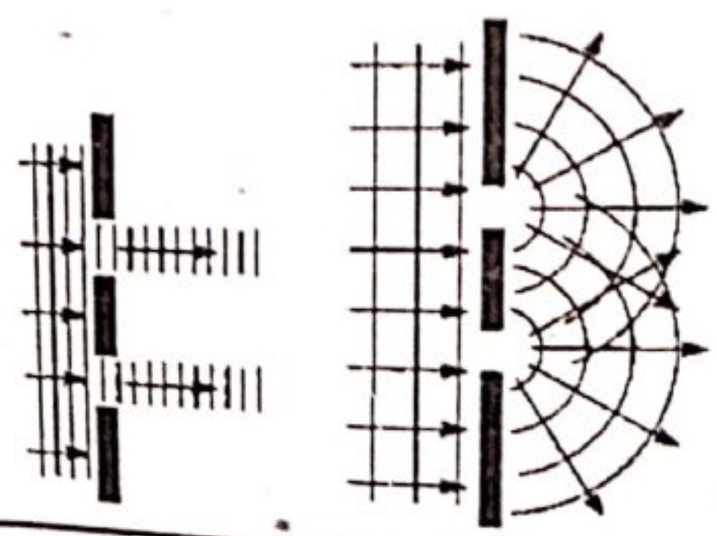
A point source of light placed at principal focus of convex lens will produce a plane wave.

HUYGEN'S PRINCIPLE

(i) Every point on wave front acts as a source of secondary spherical wavelets, which propagate in forward direction with speed of light.

(ii) Position of new wave front is tangent envelope to all of secondary wavelets.

(iii) Radius of hemisphere = $c\Delta t$



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- There is an infinite number of secondary wavelets present on wave front.
- Light ray is associated with direction of flow of light energy.
- In a homogeneous medium, the energy of wave is transmitted equal in all sides and wave front remains spherical for long distance

INTERFERENCE OF LIGHT

Interference is a superposition of two light waves of same frequency and same amplitude propagating in same medium along same direction very close to each other.

- For constructive interference, light waves reach a point **in phase** and their path difference $= n\lambda$
- For destructive interference, light waves reach a point in **out of phase** and their path difference $= (2n+1)\frac{\lambda}{2}$

Conditions for Interference of Light

(i) Monochromatic (Having single wave length)
(ii) Coherence (Having constant phase difference)
(iii) Same direction
(iv) Same medium
(v) Very Close to each other.

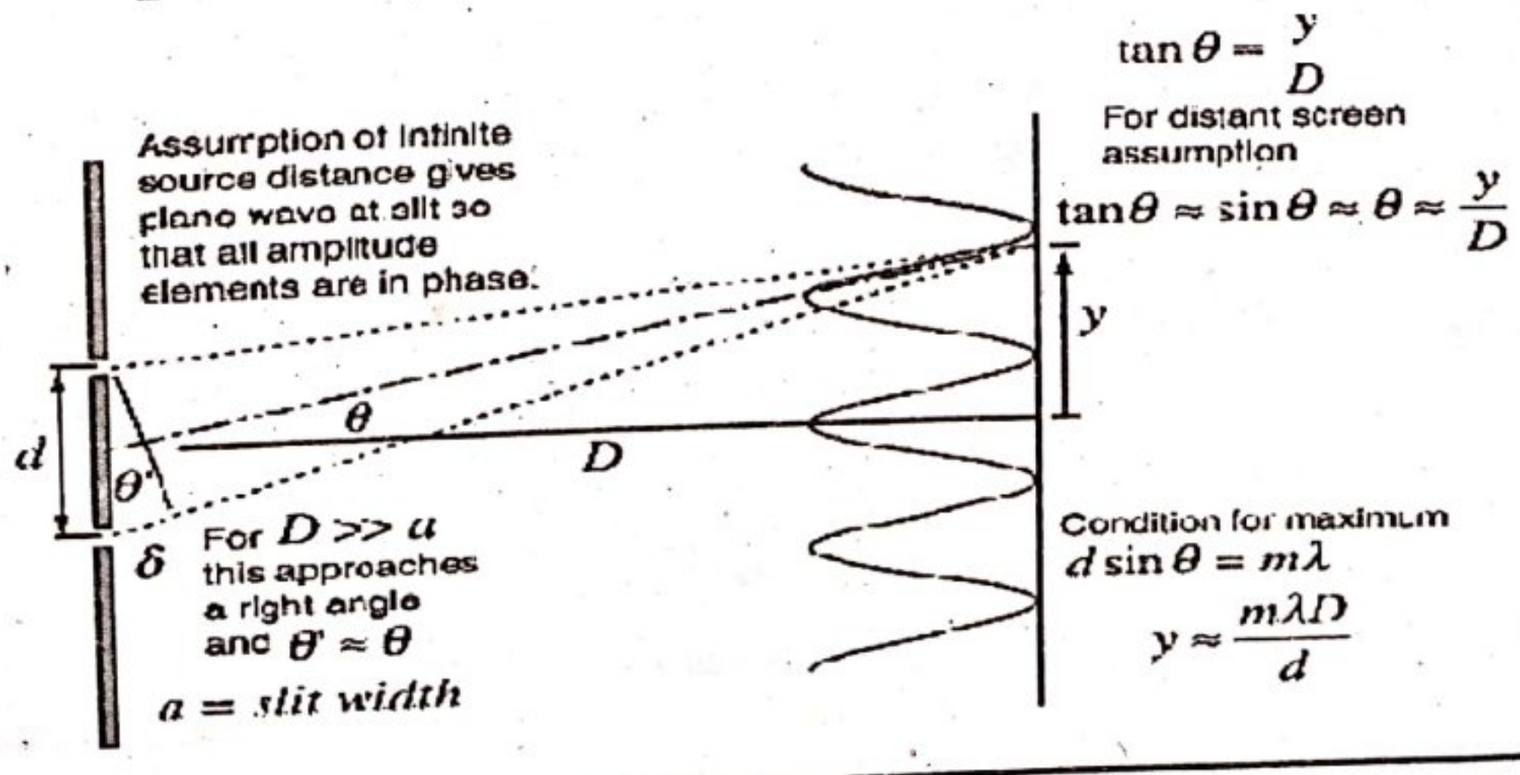
- There is no perfect monochromatic source, but by using filters it is possible to produce a source that gives light whose wavelength differ by $\pm 5 \times 10^{-10}$ m
- If phase difference between two waves remains constant, then interference pattern will be stationary on screen otherwise it will change continuously.
- For two ordinary sources, no interference pattern is obtained, because the phase changes rapidly and irregularly (that's why to get two coherent waves a single beam of light is split into two or more beams).
- Optical path is equal to product of refractive index of medium and distance covered in air.

Optical path = nd

where 'n' is refractive index and 'd' is path in air.

YOUNG'S DOUBLE SLIT EXPERIMENT

- Path difference $= d \sin\theta$
- For bright fringes;
  $d \sin\theta = m\lambda$ 1st bright fringe at $m = 0$
- For dark fringes;
  $d \sin\theta = (2m+1)\frac{\lambda}{2}$ 1st dark fringe at $m = 0$



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- $y_m = \frac{m\lambda D}{d}$ (position of mth bright fringe)
- $y_m = (2m+1)\frac{\lambda D}{2d}$ (position of mth dark fringe)
- $\lambda = y_m \frac{d}{mD}$ (wavelength from bright fringe)
- $\lambda = 2y_m \frac{D}{(2m+1)d}$ (wavelength from dark fringes)
- Distance between centers of two consecutive dark fringes or bright fringes is called fringe width.

$$F.W = \frac{\lambda D}{d}$$ (applicable both for bright or dark fringes)

Suggestions to widen the interference fringes

F.W. $\propto \lambda$ (to increase λ)
F.W $\propto$ D (to increase D)
F.W $\propto$ 1/d (to decrease d)

INTERFERENCE IN DIFFERENT TYPES OF THIN FILMS

- Thin film of refracting medium having thickness comparable to the wavelength of light rays e.g. **(i)** Oil film on water **(ii)** Soap film **(iii)** Air film
- When exposed to white light, thin film produces colorful pattern due to interference.
- When exposed to monochromatic light, only bright and dark fringes are obtained

Classification of Thin Films

Uniform or Parallel Thin Films

Whose thickness is uniform. It gives straight interference pattern.

Wedge-Shaped Films

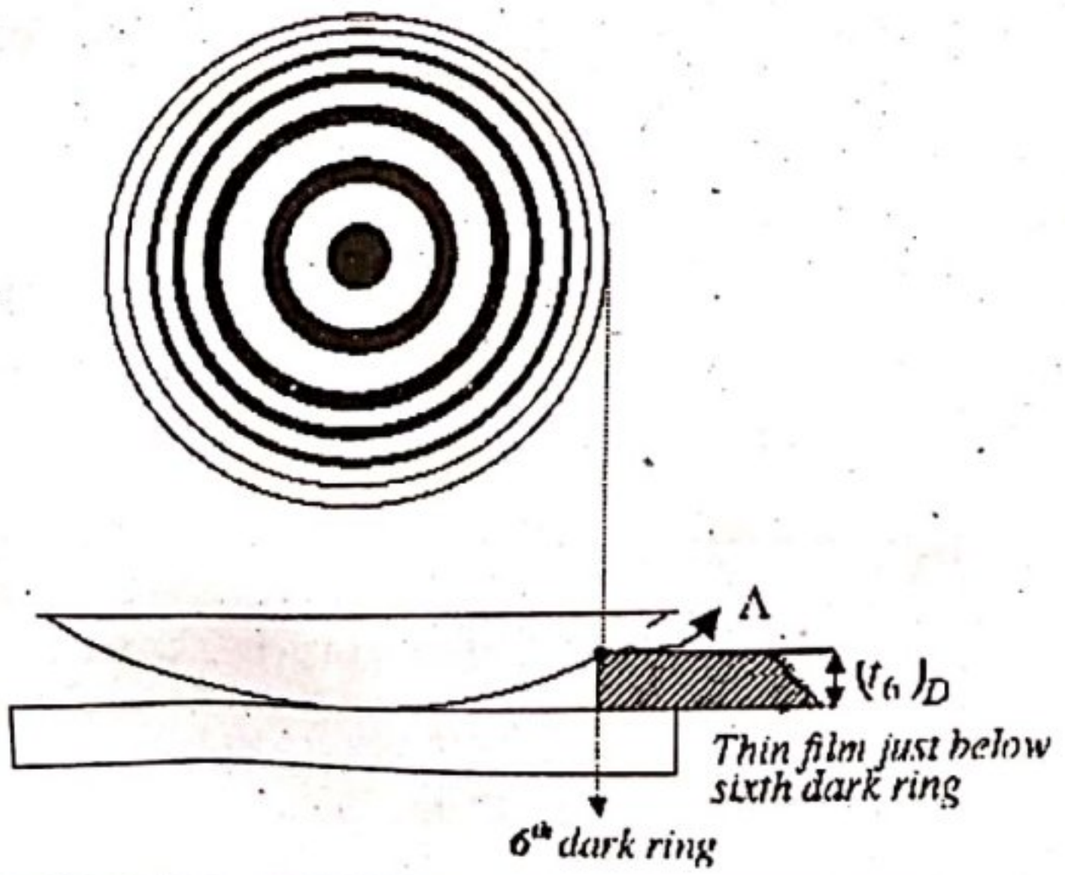
Whose thickness is zero at one end and then increases uniformly. Its interference pattern comprises a set of parallel fringes all parallel to the edge of wedge.

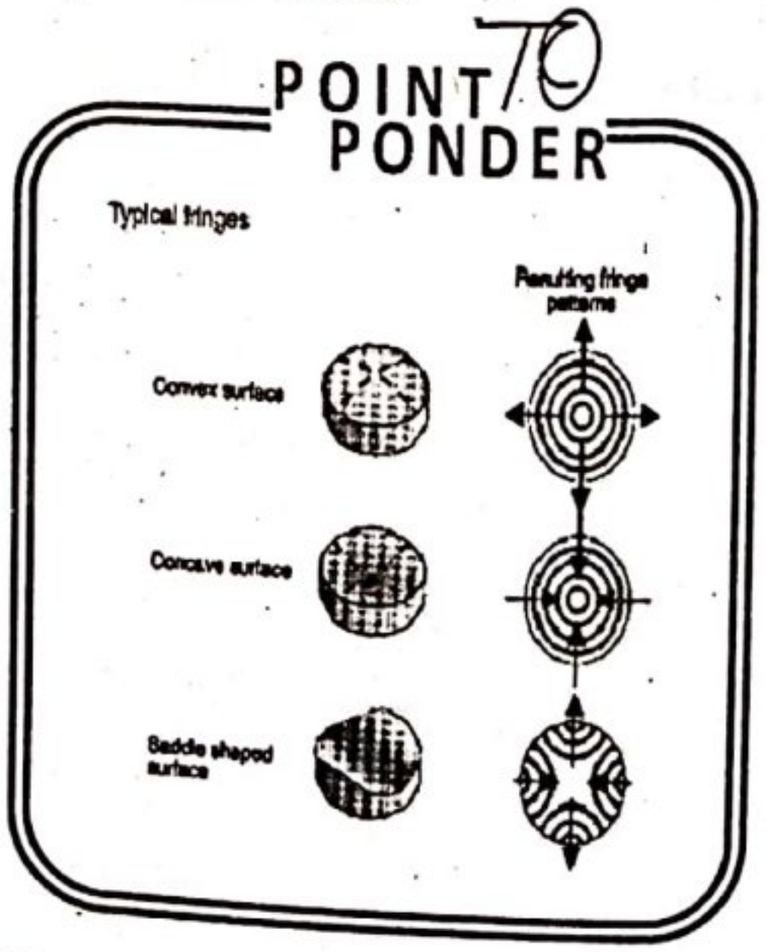


- Wedge shaped films can be obtained using a spacer between the two slides of glass.
- The thinnest part of wedge film shaped is always dark, due to additional path difference of $\lambda/2$, caused by phase reversal, at denser medium.

NEWTON'S RINGS

- Newton's rings are practical study of interference in wedge shaped thin films.





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(i) When sodium light is incident on the plano convex lens system, light rays reflect from upper and lower layers of the air present between lens and the glass plate. The sodium light source is almost monochromatic.
(ii) There is no phase change at the lens-air surface, because the wave is going from a higher to a lower refraction index medium. At the air-plate surface, however, there is a phase shift of 180^0 with the reflection from a medium of higher refractive index.
(iii) Waves reflected from these two surfaces interfere, forming bright bands where the path length in air produces two waves in phase and dark bands where the waves are out of phase.
(iv) The centre of the pattern is black.
(v) The fringes are circular as the locus of points of equal thickness of air is a circle.

- Conditions for interference are reversed for Newton's rings as;

$$\text{Path difference} = m\lambda \quad \text{(for dark ring)}$$

$$\text{Path difference} = (2m+1)\frac{\lambda}{2} \quad \text{(for bright ring)}$$

This is due to **phase reversal by 180°** which is equivalent to an extra path difference of $\frac{\lambda}{2}$.

- Point of contact is always dark due to **phase reversal** at point of contact. Here actual physical path difference is zero.

PRIMARY AND SECONDARY COLOURS

Red, green and blue colours are called primary colours. Complementary colours of white light are those two colours, whose combined effect is to produce white light on eye. They are;

(i) Red and blue - green
(ii) Yellow and blue - violet
(iii) Green and purple (mixture of red and blue)

If two primary colours of white light are mixed, we get complementary colours. e.g. red and green primary colours are mixed, we get yellow, which is complementary colours of blue-violet.

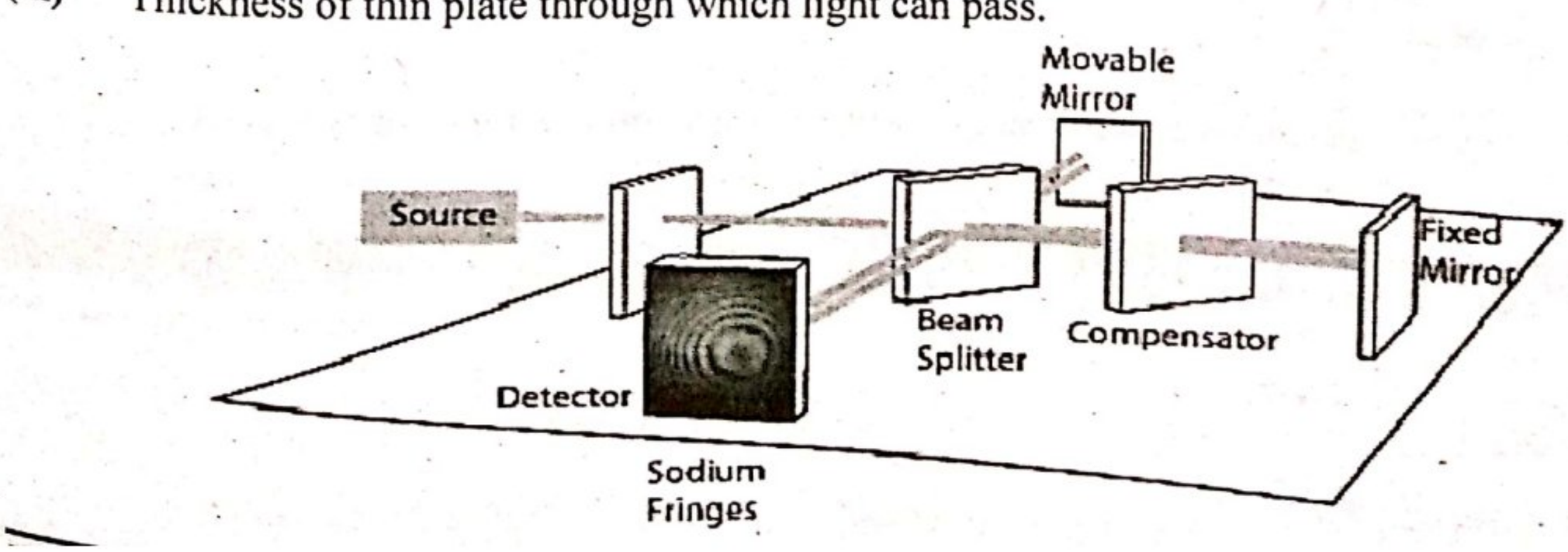
DIFFERENCES BETWEEN LUMINOUS, NON-LUMINOUS AND INCANDESCENT OBJECTS

- A luminous object is one that emits its own light e.g. sun
- A non-luminous object is that which is visible by light it reflects. e.g. moon
- Incandescent object is that which emits light due to heating, e.g. filament of electric bulb.

MICHELSON INTERFEROMETER

- Michelson interferometers is an optical instrument used for following purposes;

(i) Testing lenses, mirrors and prisms.
(ii) Measurement of refractive indices.
(iii) Thickness of thin plate through which light can pass.



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- Interferometers are based upon the principle of division of wave front
- Michelson's interferometer consists of following essential parts;

(i) Diffused source of monochromatic light.
(ii) Beam splitter (semi-silvered glass plate).
(iii) Plane mirrors held ⊥ to each other, one is fixed and the other is movable.
(iv) Micrometer (it is attached to movables mirror)
(v) Compensator (glass plate equal in thickness to beams splitter and of the same material as that of beam splitter).
(vi) Telescope (to observe interference fringes)

- If mirror is moved by a distance of $\lambda/2$, with **dark fringe in view**, then fringe of same kind is observed because **total path difference is λ.**
- If mirror is moved by distance of $\lambda/4$, **then alternatively, dark and** bright fringes can be observed because **total path difference is $\lambda/2$.**
- If mirror is moved through distance p, and 'm' fringes pass before eye.

$$p = \frac{m\lambda}{2}$$

- Interferometer can be used:

(i) To determine refractive index
(ii) To test planes of glass slabs and lenses
(iii) To determine wavelength of light

DIFFRACTION OF LIGHT

Bending of light around sharp edges is called diffraction or the spreading of light waves into geometrical shadow of an obstacle and redistribution of light intensity resulting in dark and bright fringes is called diffraction of light.

- The smaller is the size of diffracting object (obstacle), the higher the degree of diffraction is observed.

Differences between interference and diffraction

INTERFERENCE	DIFFRACTION
(i) Superposition of few secondary wavelets is involved.	(i) Superposition of large number of secondary wavelets is involved.
(ii) Interference fringes are equal in size.	(ii) Diffraction fringes wide near diffracting object and become small as one move away from it.
(iii) Interference fringes are equally spaced.	(iii) Diffraction fringes become narrow as distance from diffracting object increases.
(iv) Points of destructive interference are perfectly dark.	(iv) Points of minimum intensity are not perfectly dark.

DIFFRACTION DUE TO NARROW SLIT

- Diffraction due to a narrow slit has central maximum and alternating secondary minima and maxima on its both sides.
- Condition for mth order minima on either side of center is given by

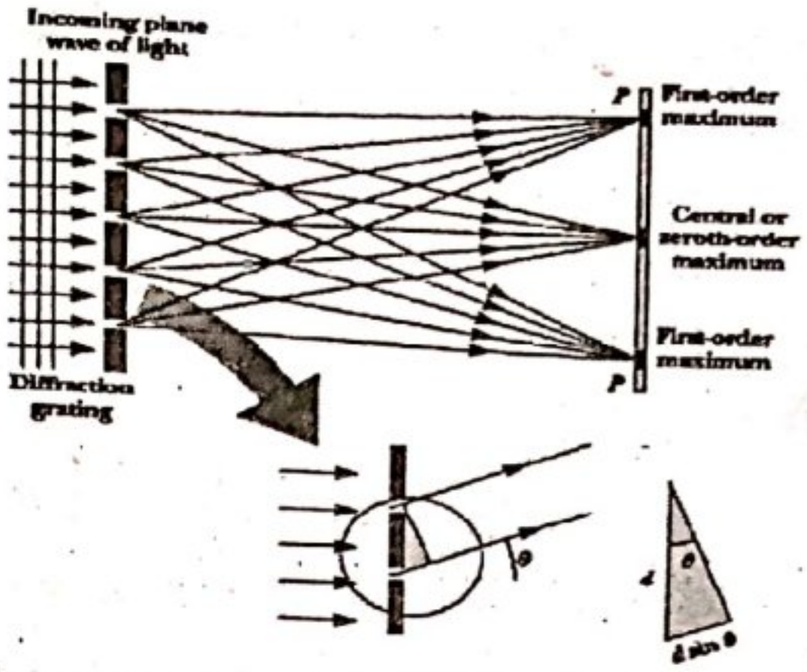
$$d \sin\theta = m\lambda$$

where $m = 1,2,3,\ldots\ldots$ And d is width of slit.

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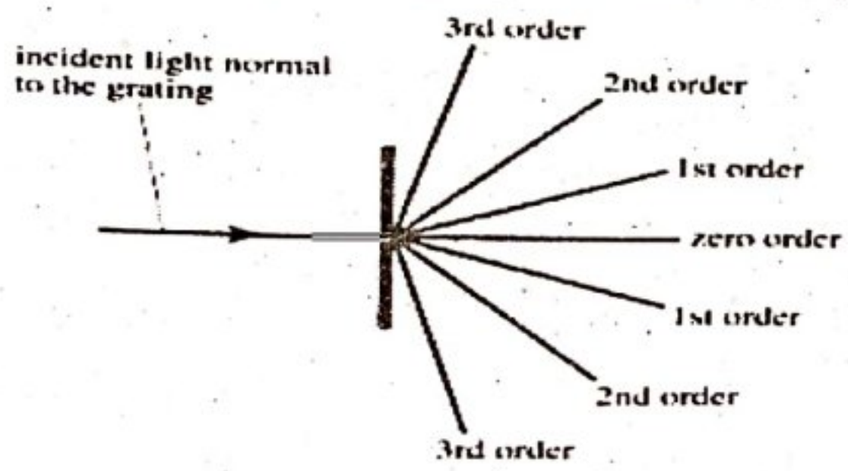
DIFFRACTION GRATING

Diffraction grating is a multi-slit arrangement of parallel and equally spaced slits.
Suppose monochromatic light is directed at the grating parallel to its axis as shown. Let the distance between successive slits be d.



The diffraction pattern on the screen is the result of the combined effects of diffraction and interference. Each slit causes diffraction, and the diffracted beams in turn interfere with one another to produce the pattern. The path difference between waves from any two adjacent slits can be found by dropping a perpendicular line between the parallel waves. By geometry, this path difference is d sin θ . If the path difference equals one wavelength or some integral multiple of a wavelength, waves from all slits will be in phase and a bright line will be observed. Therefore, the condition for maxima in the interference pattern at the angle θ is **d sin θ = m λ** where **m = 0,1,2,3…..**

Because d is very small for diffraction grating, a beam of monochromatic light passing through a diffraction grating splits into very narrow maxima (bright fringes) at large angles θ.



POINT TO PONDER

Practically a diffraction grating is a piece of glass with 400 → 5000 lines per cm.

- Lines are opaque while separation between them is transparent, so space between two engraved lines behaves as slit.
- Distance between two slits is called grating element. **d = l/N**
  where 'N' is the number of lines in one unit length.
- Grating equation is given as **d sin θ = mλ**
  where 'm' is called the order of diffraction pattern.
- For white light, we see colored fringes.
- Resolving power of grating is its ability to separate two wavelengths of light in given order of their spectrum.

Resolving Power = $\lambda/\Delta\lambda$ = N x m
N = number of lines ruled on grating
m = order of diffraction
$\Delta\lambda$ = difference in two wavelengths to be resolved by the grating.

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DIFFRACTION OF X-RAYS BY CRYSTALS

- Bragg's law is given as $2 d \sin\theta = m\lambda$

  Where'd' is called lattice spacing and θ is called angle of diffraction.
- Solid crystals behave as very good natural diffraction gratings and incident ultraviolet light is diffracted from layers of atoms.
- Inter atomic layer distance is called lattice constant.
- In 1913, Max Von Laue suggested that since atomic layers in solid NaCl have layer separation of **10^{-10} m,** therefore, **X-rays can be diffracted.**
- Max von laue pattern on film is in the form of dark spots/bright spots.
- Analysis of the relative intensity of dark/bright spots gives rise to crystal structure of solid.

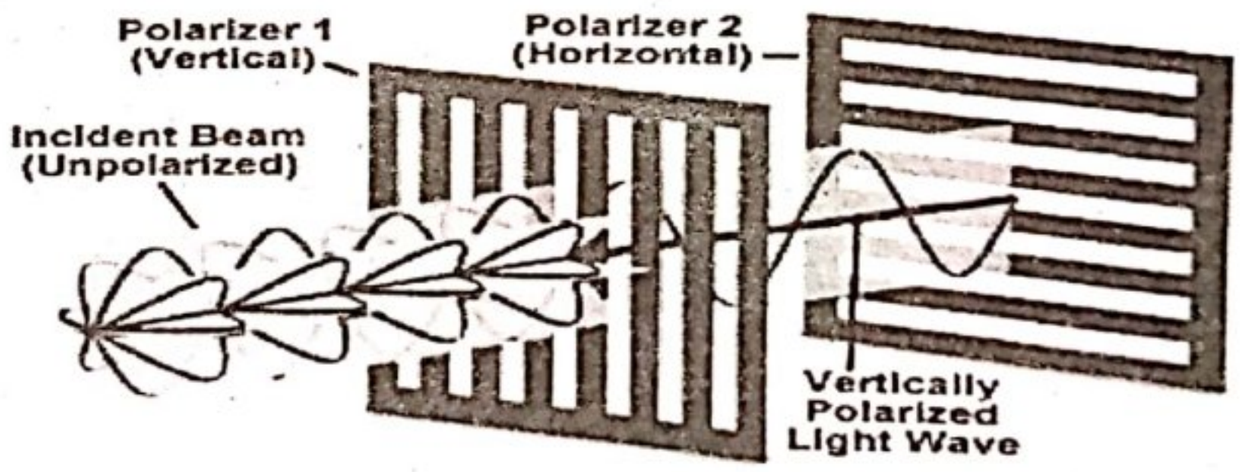
Note: Diffraction proves that wavelength of light is smaller than that of sound

POLARIZATION

Confinement of electric vectors of light into one plane is called polarization.



- The material, which produces polarization, is called polarizor. e.g. tourmaline crystal is a polarizer.



- Polariod (polarizer) absorbs all magnetic vectors as well as randomly oriented electric vectors leaving only those electric vectors, which are in one plane.
- Tourmaline crystal has internal molecular structure such that their interaction with incident light is to;

(i) absorb all magnetic vectors

(ii) put (confine) all electric vector in one plane.

- Polarization is possible only in e.m waves because their electric and magnetic vectors are $\perp$ to each other as well as well to direction of propagation. **Thus, polarization has established that light is a transverse wave.**
- Analyzer is used to test plane polarization.

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- Plane determined by direction of propagation and polarized electric vectors of light is called plane of polarization.
- Malus Law : $I = I_0\cos^2\theta$
- Different methods for producing plane polarized light are given below;

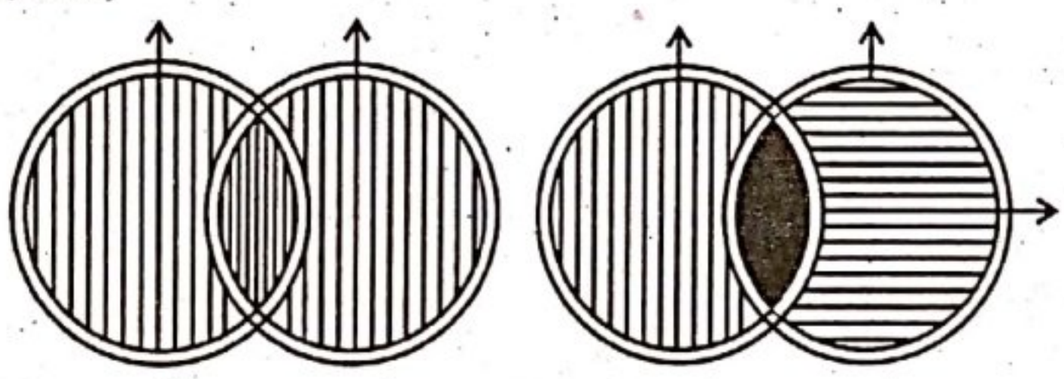
(i) Selective absorption technique (e.g. tourmaline crystal, calcite, crystal)
(ii) Polarization by reflection.
(iii) Polarization by scattering.

INTENSITY OF LIGHT EMERGING FROM A POLAROID

- Intensity is given as $I = I_o\cos^2\theta$
- If the two polaroids have their transmission axes parallel to each other, i.e., $\theta' = 0^o$

  $\therefore \quad \mathbf{I = I_o\cos^2 0 = I_o\,(max)}$
- If the two polaroids are crossed, i.e., have their transmission axes perpendicular to each other, $\theta = 90^o$

  $\therefore \quad \mathbf{I = I_o\cos^2 90 = 0(min)}$



(a) Parallel Polaroids **(b) Perpendicular Polaroids**

Uses of Polarized Light

(i) Determination of concentration of optically active substance in a solution, e.g. sugar in blood & urine by using polarimeter in medical diagnostic labs.
(ii) Curtainless window.
(iii) To enhance effect of clouds & sky in photograph.
(iv) Headlights of vehicles to control the glare in night driving.

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10 CHAPTER OPTICAL INSTRUMENTS

LENS

- Lens is a piece of transparent medium bounded by two surfaces at least one of which is curved.
- Every lens is a part of some sphere.

Types of Lenses

Convex Lens: It is thicker at the middle and thinner at the edges.

Concave Lens: It is thinner at the middle and thicker at the edges.

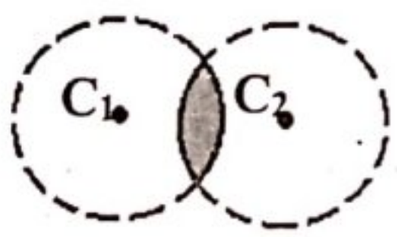
Types of Convex and Concave Lenses

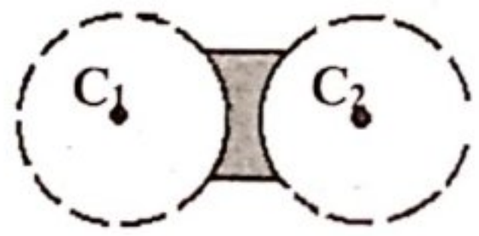
SR. NO.	CONVEX LENS		CONCAVE LENS	
1	Double convex		Double concave	
2	Plano convex		Plano concave	
3	Concavo convex		Convexo concave	

Important Definitions

Centre of Curvatures

Centre of sphere from which spherical surface of lens is obtained.

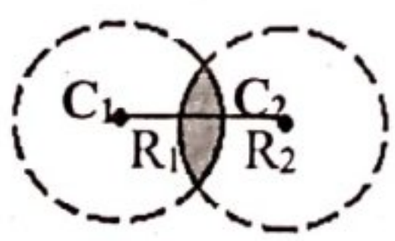


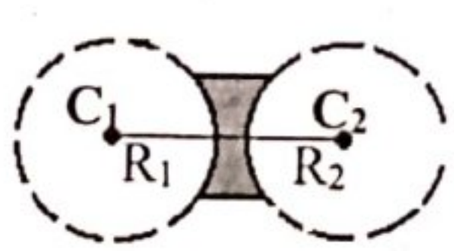


Every lens has two centers of curvatures.

Radius of Curvature

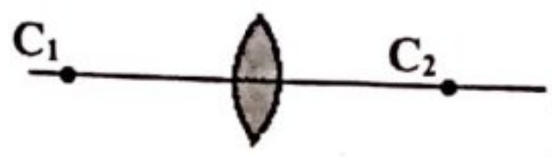
Radius of sphere from which spherical surface of lens is obtained.

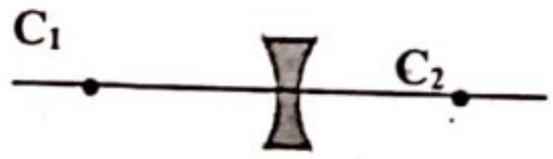




Every lens has two radii of curvature that may not be equal.

Principal axis is the line joining its two centers of curvature.

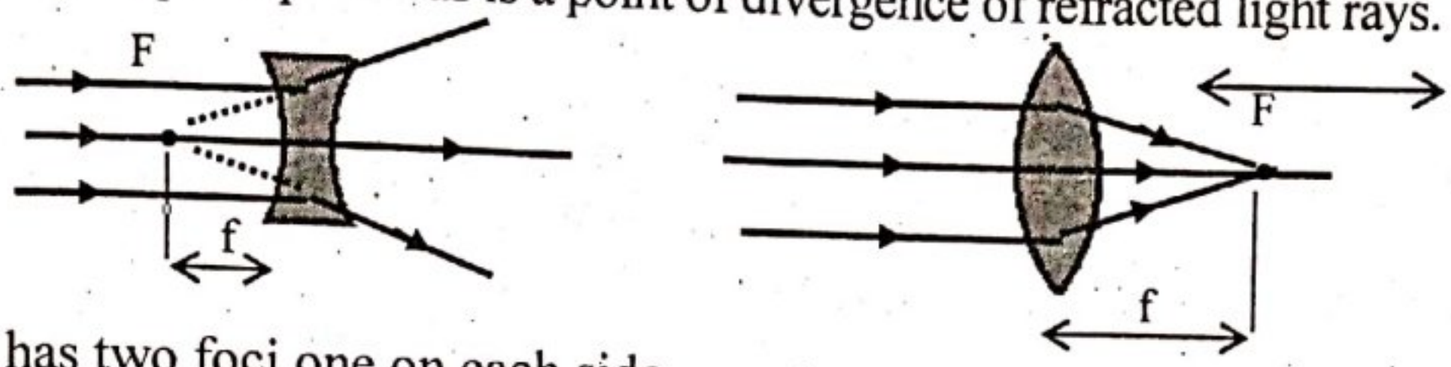




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Principal Focus

(a) For convex lens, principal focus is a point of convergence of refracted light ray. It is a real point.
(b) For concave lens, principal focus is a point of divergence of refracted light rays. It is imaginary point.



Every lens has two foci one on each side.

Optical Centre is a point inside the body of lens through which light rays pass, undeviated.

Focal Length is a distance between principle focus and optical center. It is positive for convex lens and negative for concave lens.

Note: It is not necessary that two focal lengths are equal for a lens.

Aperture is the size of diameter of lens.

Power of a Lens is its ability to deviate light ray from its original path.

$$P = 1/f$$

where 'f' is focal length in meter.

If 'f' is in cm, then-

$$P = 100/f$$

- SI unit of power of lens is dioptre.

$P = 1D$ if $f = 1m$

COMBINATION OF LENSES

General rule for combination of 'n' lenses

General rule for combination of 'n' lenses is

$$P = P_1 + P_1 + \text{----------} + P_n$$

Examples

For two double convex lenses;

$$P = P_1 + P_2$$

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\frac{1}{f} = \frac{f_1 + f_2}{f_1 f_2}$$

$$f = \frac{f_1 f_2}{f_1 + f_2}$$



Thus combination behaves as a convex lens.

For two concave lenses;

$$P = P_1 + P_2$$

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\frac{1}{f} = \frac{-(f_1 + f_2)}{f_1 f_2}$$

$$\frac{1}{f} = \frac{-f_1 f}{f_1 + f_2}$$



Thus combination behaves as a concave lens.

For one convex and other concave lens;

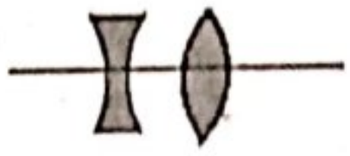
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$$P = P_1 + P_2$$

$$\frac{1}{f} = \frac{1}{f_1} - \frac{1}{f_2}$$

$$\frac{1}{f} = \frac{f_2 - f_1}{f_1 f_2}$$

$$f = \frac{f_1 f_2}{f_2 - f_1}$$



Thus combination may behave as a convex or concave lens.

Lens Formula

- General lens formula is given as;

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

p is +ve for real object and -ve for virtual object.
q is +ve for real image and -ve for virtual image.
f is +ve for convex lens and -ve for concave lens.

- For different cases, we have to modify it.

Examples

For a virtual object;

$$\frac{1}{p} + \frac{1}{-q} = \frac{1}{f}$$

For concave lens;

$$\frac{1}{p} + \frac{1}{-q} = -\frac{1}{f}$$

POINT TO PONDER

Positive sign is used where rays actually intersect. If not then we can use negative sign

Position and Nature of Image for Convex Lens

Position of object	Position of image	Nature of image
Beyond 2F	Between F and 2F	Real, inverted, small
At 2F	At 2F	Real, inverted, equal
Between F and 2F	Beyond 2F	Real, inverted, enlarged
At F	At infinity	Real, inverted, enlarged
Inside F	On same side further away from lens than the object	Virtual, erect, enlarged

MAGNIFICATION OF A LENS

- Linear magnification is given as;

$$M = \frac{q}{p} = \frac{h_i}{h_o} = \frac{\text{size of image}}{\text{size of object}}$$

POINT TO PONDER

For very small angles we can equate linear and angular magnifications

- Angular magnification is given as;

$$M = \frac{q_i}{q_o} = \frac{\text{Angle formed at aided eye}}{\text{Angle formed at naked eye}}$$

- For real image;

$$M = \frac{q}{p}$$

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- For virtual image;

$$M = \frac{-q}{p}$$

Visual Angle

- Visual angle is angle made by object at observer's eye.
- Apparent size of object varies with visual angle.
- Apparent size ∝ visual angle

Resolving Power

The resolving power of an instrument is its ability to reveal the minor details of the object under examination.

Angle of Resolution

The minimum angle that allows two point sources to appear distinctly separated is called angle of resolution. It is expressed as $\alpha_{.min}$, $\alpha_{min} = 1.22\frac{\lambda}{D}$

Raleigh showed that resolving power of a lens of aperture D, under a light source of wavelength λ is.

$$R = \frac{D}{1.22\lambda}$$

LENS ABERRATIONS

Spherical Aberration

It is the formation of blurred image due to size of lens because outer rays undergo more refraction than the inner ones.

Remedy

Provide such constraints on the lens that allows only paraxial rays to enter the lens.

Chromatic Aberration

It is the inability of a lens to bring all light rays (all colours) at single focus. Multicoloured blurred image is formed.

Remedy

Use the combination of convex and concave lenses called as achromatic lenses.

LEAST DISTANCE OF DISTINCT VISION

It is the minimum distance at which a normal eye can see an object clearly. d = 25cm

POINT TO PONDER

As we get over the years up to old age the value of least distance of distinct vision is drastically affected

OPTICAL INSTRUMENTS

Optical instruments are those, which use light for their operations e.g.

(i) Simple microscope (ii) Compound microscope (iii) Telescope
(iv) Camera (v) Michelson interferometer (vi) Spectrometer
(vii) Periscope

SIMPLE MICROSCOPE

Simple microscope (magnifier) is a double convex lens of short focal length. ⇒ Its magnifying power is;

$$M = 1 + \frac{d}{f}$$

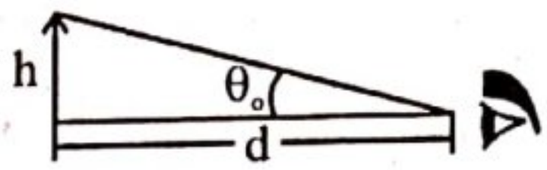
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d = 25 cm

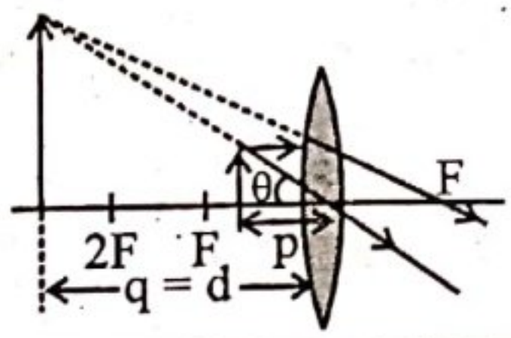
f = focal length.

✦ It forms virtual, erect and magnified image at d.

$$M \propto \frac{1}{f}$$



Unaided-eye



COMPOUND MICROSCOPE

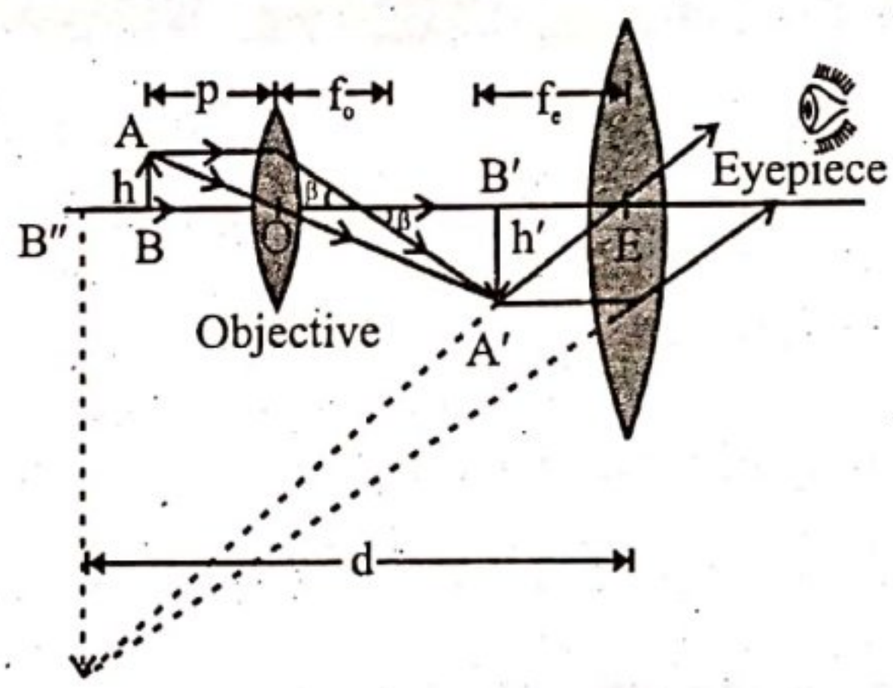
Compound microscope consists of two convex lenses.

(a) Objective lens of small size and short focal length.

(b) Eyepiece lens of large size and large focal length.

A compound microscope uses a very short focal length objective lens to form a greatly enlarged image. This image is then viewed with a short focal length eyepiece used as a simple magnifier.

The general assumption is that the length of the tube L is large compared to either f_o or f_e so that the following relationships hold.



$M = \frac{L}{f_o}\left(1 + \frac{d}{f_e}\right)$ where L is the distance between two lenses (eyepiece and objective).

POINT TO PONDER

A wider objective and use of blue light of short wavelength produces less diffraction and allows more details to be seen

Note:

(a) $f_o < f_e$ always otherwise it will becomes astronomical telescope.

(b) In case of expensive microscopes, eye-piece and objectives are combination of lenses to reduce lens defects.

(i) Objective forms real image while eyepiece forms virtual image.

(ii) Magnification of objective = $\frac{L}{f_o}$

(iii) Magnification of eyepiece = $1 + \frac{d}{f_e}$

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TELESCOPE

Telescope is an optical instrument, which enables the observer to see fine details of a far off object.

- Two major classes of telescopes are given below:

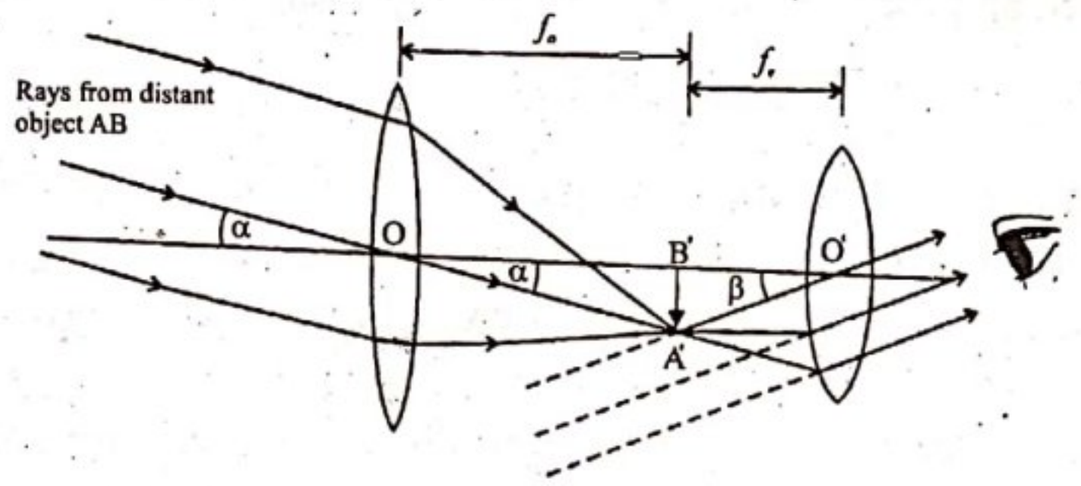
(i) Reflecting telescopes — Astronomical
(ii) Refracting telescopes — Galilean, Terrestrial

ASTRONOMICAL TELESCOPE

- It is used to see images of heavenly bodies.
- It consists of two lenses.

(a) **Objective** is double convex lens of large focal length and large aperture.
(b) **Eyepiece** is a double convex lens of short focal length and small aperture.

- When set for infinity or parallel rays, then; $\mathbf{L = f_o + f_e}$



Advantages:

(i) High magnifying power

$$M = \frac{f_o}{f_e}$$

(ii) Large field of view.

Disadvantages:

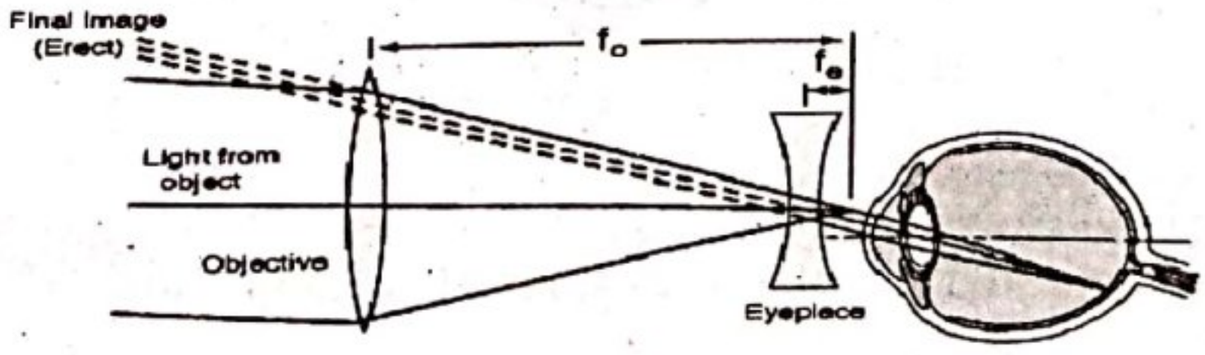
Final image is inverted.

POINT TO PONDER

A good telescope has an objective of long focal length and large aperture

GALILEAN TELESCOPE

The Galilean or terrestrial telescope uses a positive objective and a negative eyepiece. It gives erect images and is shorter than the astronomical telescope with the same power. It's angular magnification is $-\frac{f_o}{f_e}$.



Defects of Vision

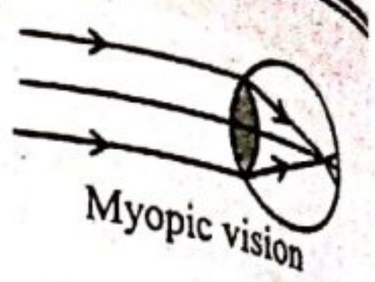
In case of eye following are the common defects of vision:

- Myopia (or short-sightedness or Near-sightedness)
- Hyperopia (also known as hypermetropia or longsightedness or Far-sightedness).
- Presbyopia
- Astigmatism

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Myopia (Or Short-Sightedness or Near-Sightedness):

Cause: In it distant objects are not clearly visible, i.e., far point is at a distance lesser than infinity and hence image of distant object is formed before the retina.

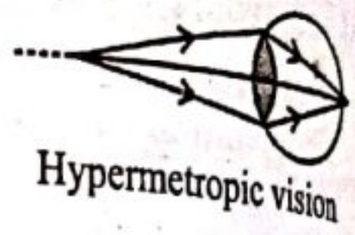


Remedy: This defect is remedied by using spectacles having divergent lens (i.e., negative focal length or power) which forms the image of distant object at the far point of patient (which is lesser than ∞).

Hyperopia (Long Sightedness or Far-Sightedness):

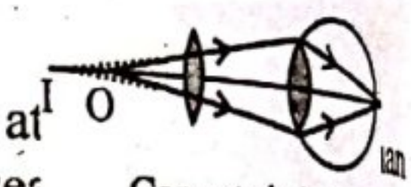
Cause: In it near objects are not clearly visible, i.e., near point is at a distance greater than 25 cm. image of near object is formed behind the retina.

Remedy: This defect is remedied by using spectacles having convergent lens (i.e., positive focal length or power) which forms the image of near objects at the near point of the patient eye (which is more than 25 cm).



Presbyopia:

Cause: In this both near and far objects are not clearly visible, i.e., far point is at infinity and near point at a distance greater than 25 cm. it is an old age disea muscles lose their elasticity and so cannot change the focal length of eye-lens effectively and hence eye loses its power of accommodation.



Remedy: This is remedied either by using two separate spectacles one for myopia and the other for hypermetropia or using single spectacle having bifocal lenses.

SPECTROMETER

It is an optical instrument used to study spectrum of light.

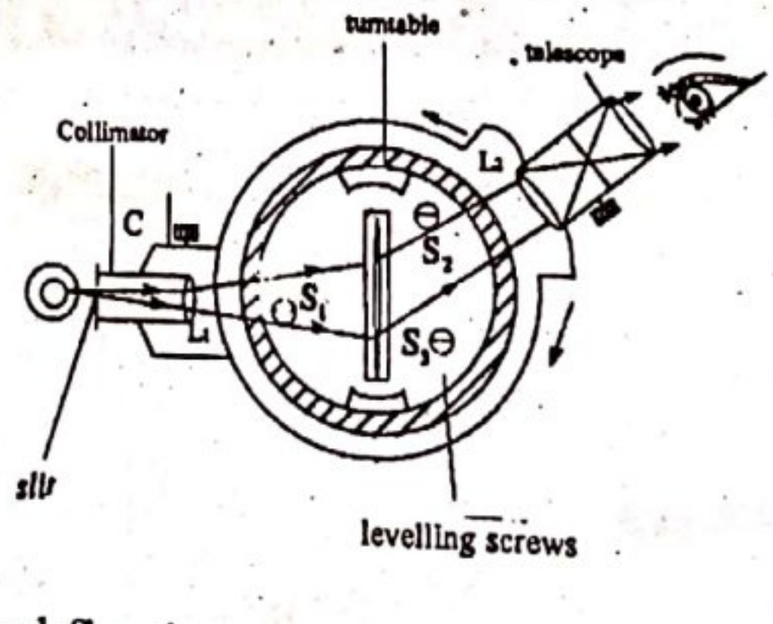
- It has following parts: -

(i) Collimator: It has slit at focus of a double convex lens to get a parallel beam of light.

(ii) Telescope: It is an astronomical telescope.

(iii) Turn Table: Prism or diffraction grating is placed on table called turn table.

(iv) Leveling Screws



Working

(i) Telescope is set for infinity and fixed.

(ii) Source of monochromatic light is placed in front of slit and collimator is adjusted for parallel rays.

(iii) Angle of minimum deviation (D_m) is experimentally determined.

Then refractive index of prism is given as;

$$m = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

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Where 'A' is angle of prism or apex angle.

(iv) For wavelength of monochromatic light diffraction grating is used.

$$d \sin\theta = m\lambda$$

$$\lambda = \frac{d \sin\theta}{m}$$

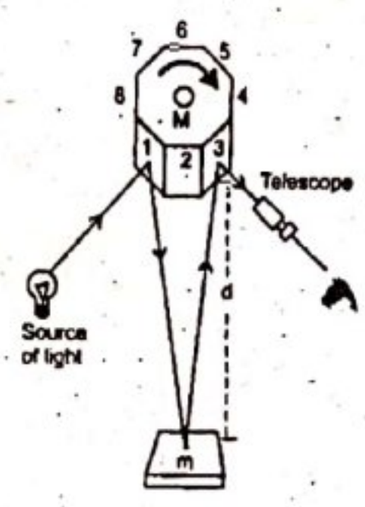
Usually m = 1 (first order diffraction),

d = grating element

$d = \frac{1}{N}$ where N is the number of rulings per centimeter

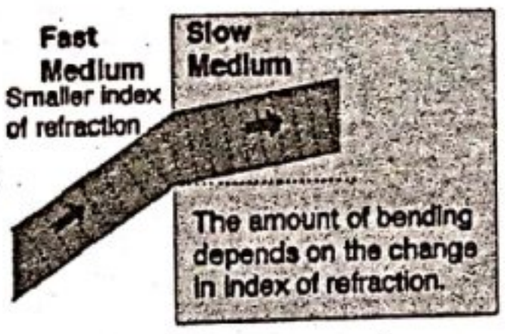
SPEED OF LIGHT

- First attempt to measure the speed of light was made **by Galileo**
- First time speed of light measured accurately by Michelson
- The Michelson's formula for determination of speed of light is **c =16 f d**
  Where f is frequency of rotation of octagonal mirror and d is distance between plane mirror and octagonal mirror.



Index of Refraction

The index of refraction is defined as the speed of light in vacuum divided by the speed of light in the medium.



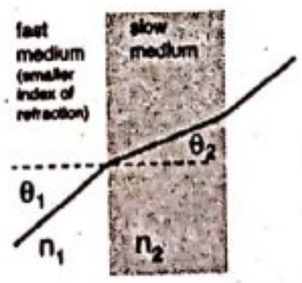
Index of refraction $n = \frac{c}{v}$ — c: velocity of light in vacuum; v: velocity of light in the medium

Snell's Law

Snell's Law relates the indices of refraction n of the two media to the directions of propagation in terms of the angles to the normal.

Snell's Law

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$



INTRODUCTION TO FIBRE OPTICS

- Graham Bell invented **photo phone to** transmit voice massage via beam of light.
- In optical fiber, light is used as a **transmission carrier wave.**
- The principle of transmitting signals through optical fibre is

(i) Total internal reflection

(ii) Continuous refraction

- Optical fibre is a fine glass rod having diameter in the range of micrometers

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Classification of Optical Fibres

Single Mode Step Index Fibre

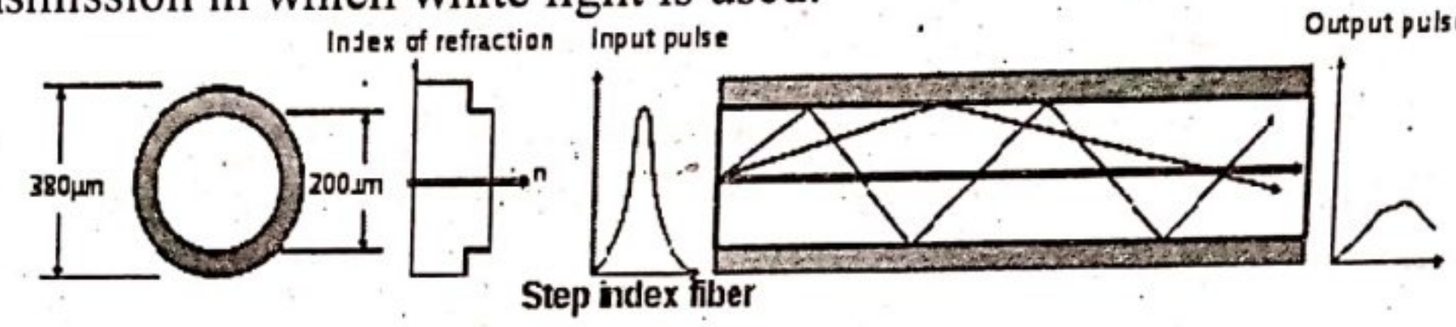
It is also called mono mode fibre & has very **narrow** core of diameter about 5 μm.

Multimode Step Index Fibre

It has larger core (50μm) of constant refractive index. Refractive index change at the boundary of core and cladding. It is useful for a short distance only. The mode of transmission in it is total internal reflection.

Multimode Graded Index Fibre

In it, core has diameter from 50 to 1000 μm. There is no noticeable boundary between core and cladding. The mode of transmission of light in it is continuous refraction. It is suitable for long distance transmission in which white light is used.



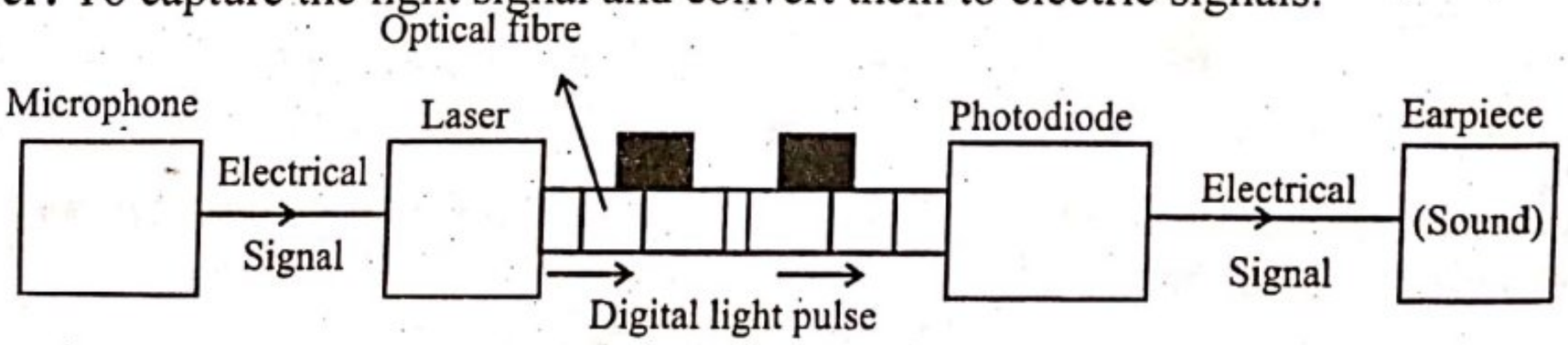
Signal Communication

- Fibre optic communication system consists of three parts

(i) **Transmitter:** To convert electrical signals to light signals

(ii) **Optical Fibre:** To guide the light signals

(iii) **Receiver:** To capture the light signal and convert them to electric signals.



- Light signals travel through fibre in `on` and `off` fashion called digital modulation. A light pulse **represents, 1 and** absence of light **represents 'O'**

Advantages of communication through optical fibre

(i) Light signals in glass travel faster than electrical signals in copper cable

(ii) More massages per cable length. (High signal strength)

(iii) Clear sound is received

Losses of Power

- Power is lost in optical fibre due to scattering of light from impurity atoms in glass
- Due to dispersion of light, signal also get weak.
- Power loss in signal due to dispersion can be reduced by using graded index fibre.
- Repeaters are used at suitable distance to overcome the power loss due to scattering from impurity atoms.

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11 CHAPTER HEAT & THERMODYNAMICS

TEMPERATURE

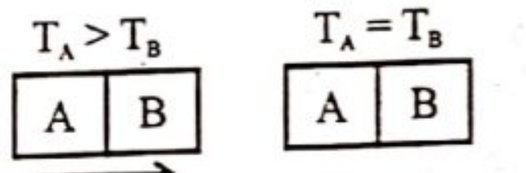
Temperature is sometimes called the degree of hotness or coldness of a body and is a quantity which is such that when two bodies are placed in contact, heat flows form the body at the higher temperature to the one at lower temperature.

HEAT

- Heat is the energy which is transferred due to difference in temperature of the bodies.
- It is a form of energy.
- The temperature of a system increases if heat is supplied to or absorbed by it.
- Temperature of system decreases when heat is taken out of the system.
- Often, if the temperature changes by an exchange of heat, then $Q = mc\,(\Delta T)$
  where m = mass, c = specific heat, $T_2 - T_1 = \Delta T$ = change in temperature
- The unit of heat in MKS is joule, in CGS, it is erg and in thermal units calorie.
- 4.2 joule = 1 calorie

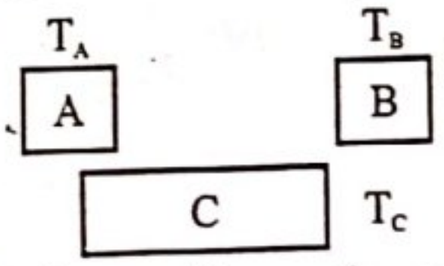
Specific Heat: The heat required to increase the temperature of unit mass of substance by 1^0C is called the specific heat of the substance. $Q = mc\Delta T$ or $c = \frac{Q}{m\Delta T}$.

Thermal Equilibrium: Objects A and B are in contact. If heat flows from A to B, then A is at a higher temperature than B. When the heat flow from A to B is zero, the two objects are in thermal equilibrium.



Zeroth Law: When two systems A and B are separately in thermal equilibrium with a third system C, then the first two systems will also be in thermal equilibrium with each other. It means if,

$T_A = T_C$ and $T_B = T_C$ then, $T_A = T_B$



Thus according to this law, temperature is that intrinsic property of an object on the basis of which, we can say that whether the object is in thermal equilibrium with another or not.

CONVERSION FORMULAS OF TEMPERATURE SCALES

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

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

(iii) $T_K = 273 + T_C$

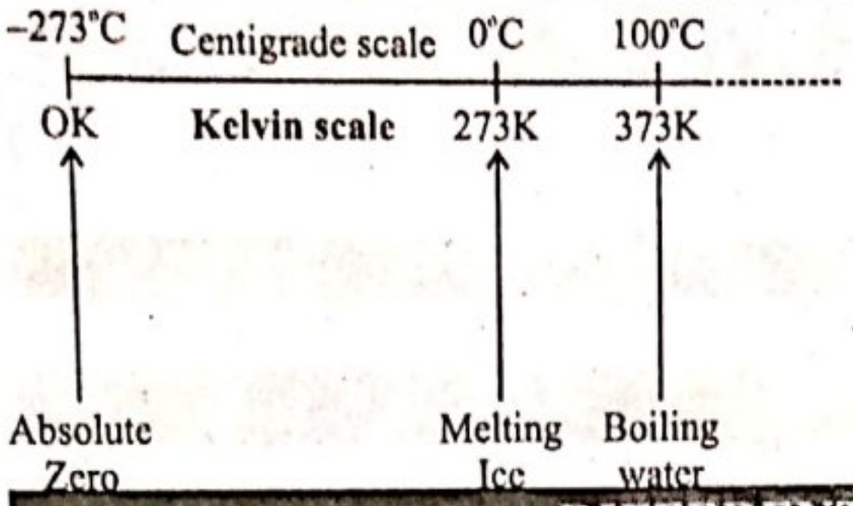
(iv) $T_K = 273 + \frac{5}{9}(T_F - 32)$

(v) $T_C = T_K - 273$

(vi) $T_F = \frac{9}{5}(T_K - 273) + 32$

Relation between °C, °F and K Temperature: $\frac{T_C - 0}{100} = \frac{T_F - 32}{180} = \frac{T_K - 273}{100}$

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POINT TO PONDER

The centigrade and Fahrenheit scale shows the same reading at a temperature of –40°

DIFFERENT SCALE OF TEMPERATURE				
Sr. #	Name of scale	Lower Point	Upper Point	Number of divisions
1	Celsius scale	0°C	100°C	100
2	Fahrenheit scale	32°F	212°F	180
3	Kelvin scale	273 K	373 K	100

POINT TO PONDER

Celsius degree is larger than a Fahrenheit degree by a factor of 9/5.

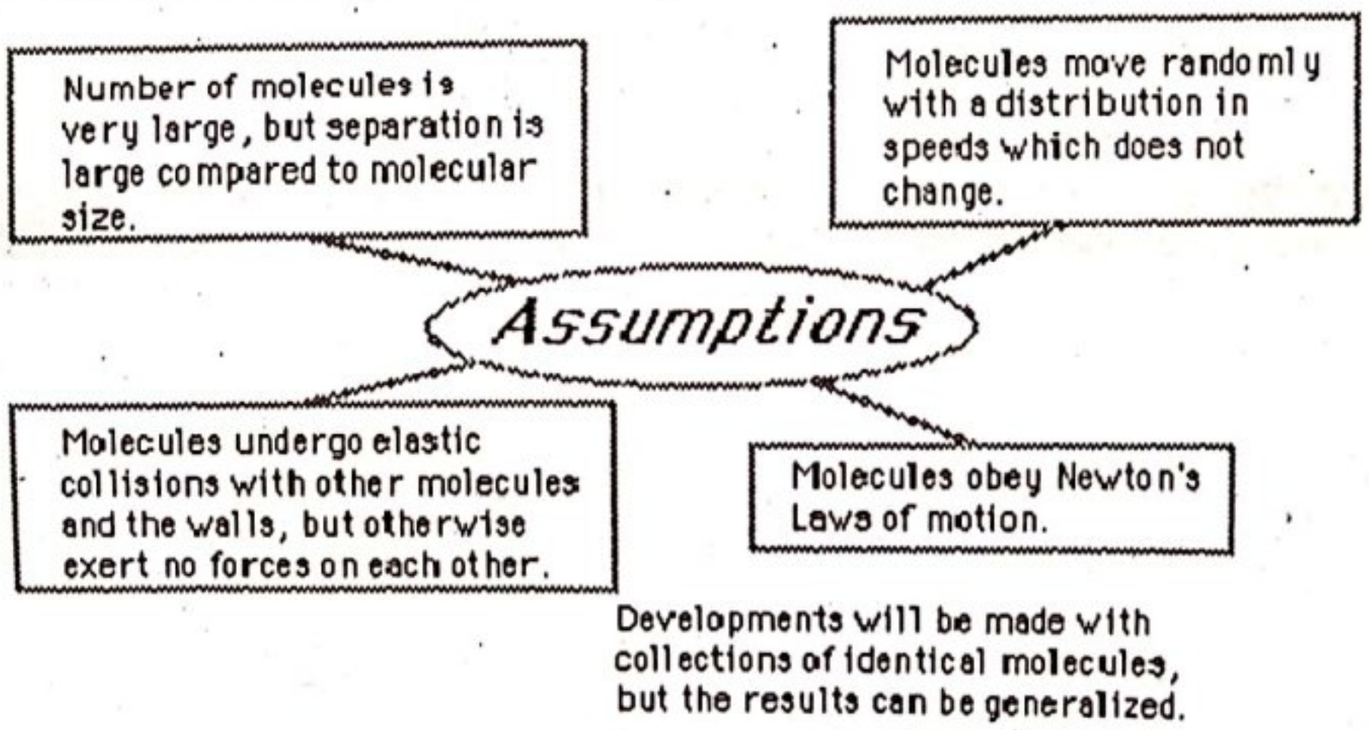
KINETIC MOLECULAR THEORY OF GASES (K.M.T)

Main points of K.M.T of gases are given as:

(i) Small volume contains large number of molecules.
(ii) Molecules move randomly and do not exert force on one another except when they collide.
(iii) Molecules collide each other elastically.
(iv) The collisions with 'walls' give rise to gas pressure.
(v) Gravity does not affect the molecular motion.
(vi) Volume of gas molecules is negligible as compared to the actual volume of the gas.

PRESSURE AND TEMPERATURE OF AN IDEAL GAS

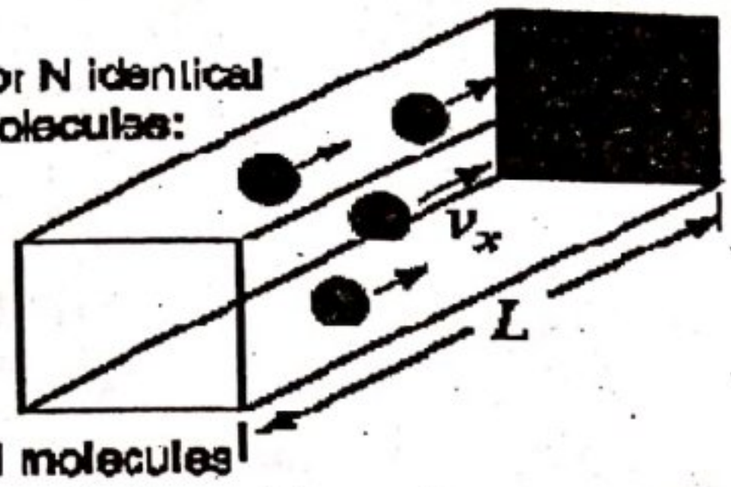
The kinetic theory of gases is the study of the microscopic behavior of molecules and the interactions which lead to macroscopic relationships like the ideal gas law.



Newton's Laws and Collisions

Applying Newton's law to an ideal gas under the assumptions of kinetic theory allows the determination of the average force on container walls. This treatment assumes that the collisions with the walls are perfectly elastic and molecules do not collide with each other.

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For N molecules

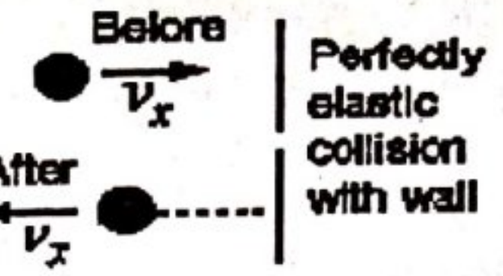
$$\overline{F} = \frac{m\left[v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \ldots \; v_{Nx}^2\right]}{L}$$

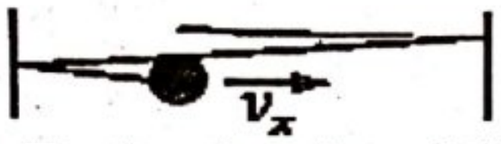
but this can be related to the average:

$$\overline{v_x^2} = \frac{\left[v_{1x}^2 + v_{2x}^2 + v_{3x}^2 + \ldots \; v_{Nx}^2\right]}{N}$$

Force of molecular collision with wall

$$\overline{F}\Delta t = \Delta p = 2mv_x$$





The time for a 'round trip' is $\Delta t = \frac{2L}{v_x}$

so the average force is $\overline{F} = \frac{2mv_x}{\frac{2L}{v_x}} = \frac{mv_x^2}{L}$

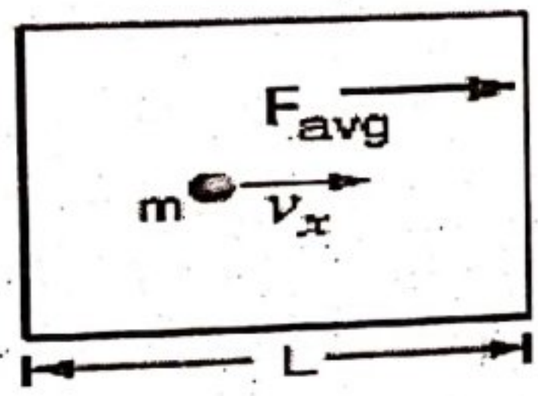
and for N molecules: $\overline{F} = \frac{mN\overline{v_x^2}}{L}$

In the expression for the average force from N molecules, it is important to note that it is the average of the square of the velocities which is used, and that this is distinctly different from the square of the average velocity.

Gas Pressure from Kinetic Theory

Under the assumptions of kinetic theory, the average force on container walls has been determined to be

$$F_{average} = \frac{mN\overline{v_x^2}}{L}$$



and by using Maxwell law of velocities distribution we get;

$$\overline{v^2} = \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2} = 3\overline{v_x^2}$$

The average force and pressure on a given wall depends only upon the components of velocity toward that wall. But it can be expressed in terms of the average of the entire translational kinetic energy using the assumption that the molecular motion is random.

then the pressure in a container can be expressed as

$$P = \frac{F_{avg}}{A} = \frac{mN\overline{v^2}}{3LA} = \frac{mN\overline{v^2}}{3V} = \frac{N}{3V}m\overline{v^2}$$

and hence the pressure is

$$P = \frac{2}{3}N_o\left\langle\frac{1}{2}mv^2\right\rangle \quad N_o = \frac{N}{V}$$

- Absolute temperature of a gas is measure of its average translational K.E of all gas molecules.

$$P = \frac{2}{3}\frac{N}{V}\langle K.E\rangle \;\; ; \;\; P\alpha\langle K.E\rangle \text{ or } P\alpha\langle v^2\rangle$$

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

$$v_{rms} = \sqrt{\langle v^2\rangle} = \sqrt{\frac{3KT}{m}}$$

POINT TO PONDER

Average speed of oxygen molecules in air at STP is 461ms^{-1}, and that for nitrogen is 493 m s^{-1}

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SPECIFIC HEATS

- Amount of heat required to raise the temperature of a substance through 1 K is called heat capacity, denoted by C.
  $Q = C\,m\,\Delta T$
- Specific heat is the amount of heat required to raise the temperature of unit mass through unit temperature.
  $Q = C\,\Delta T$

POINT TO PONDER

Molar specific heat of diatomic gas is greater than that of monatomic gas

INTRODUCTION TO THERMODYNAMICS

Thermodynamics is the study of the relationship between heat and other forms of energy.

- Thermodynamic states describe the state of a system.
- Any collection of matter having distinct boundaries is called a system.
- Boyle's law states that at constant temperature.
  $PV=K(\text{constant})$ or $P_1V_1=P_2V_2$
- Charle's law states that at constant pressure
  $\frac{V}{T} = K(cons\tan t)$ or $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
- Sum of translational K.E, rotational K.E vibrational K.E and P.E due to intermolecular forces is called internal energy.
- Internal energy of an ideal gas system is the translational K.E of its molecules.
- Increase in temperature of the object is an indication of increase in the internal energy.
- Thermodynamic work at constant pressure is $W= P\Delta V$, and if pressure is not constant then

$$W = \sum_{\Delta V_i \to 0}^{n} P_i \Delta V_i \quad where\ n \to \infty .$$

LAWS OF THERMODYNAMICS

Thermal Equilibrium

It is observed that a higher temperature object which is in contact with a lower temperature object will transfer heat to the lower temperature object. The objects will approach the same temperature, and in the absence of loss to other objects, they will then maintain a constant temperature. They are then said to be in thermal equilibrium. Thermal equilibrium is the subject of the Zeroth Law of Thermodynamics.

First Law

When heat is transformed into other forms of energy total heat remains constant.

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

Where ΔQ is +ve when heat is added and vice versa.

ΔW is –ve when work is done on the system and vice versa.

Inferences from 1st Law of Thermodynamics

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

$$\begin{pmatrix} change\ in\ internal \\ energy \end{pmatrix} = (Heat\ energy\ flowing\ in) - \begin{pmatrix} Heat\ energy\ flowing\ out \\ as\ mechanical\ work \end{pmatrix}$$

- Internal energy is a state function. i.e. depends on initial and final states
- For a cyclic process, we have-

$$\Delta U = 0 \quad , \quad U_i = U_f \quad , \quad \Delta Q = \Delta W$$

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APPLICATIONS OF 1ST LAW OF THERMODYNAMICS

- **Isothermal process** is that in which temperature remains constant.
  $\Delta Q = \Delta W$ as $\Delta U = 0$
- **Isochoric process** is that in which volume remains constant.
  $\Delta Q = \Delta U$ **as** $\Delta W = 0$
- **Isobaric process** is that in which pressure remains constant.
  $\Delta Q = \Delta U + P\Delta V$
- **Adiabatic process** is that in which no heat enters or leaves the system such that temperature remain constants: $\Delta U = -W$ **or** $W = -\Delta U$

Note: Cooling is produced when adiabatic expansion takes place and heating is produced during adiabatic compression.

Adiabatic process is also termed as isentropic process i.e. a process in which the entropy of the system remains constant.

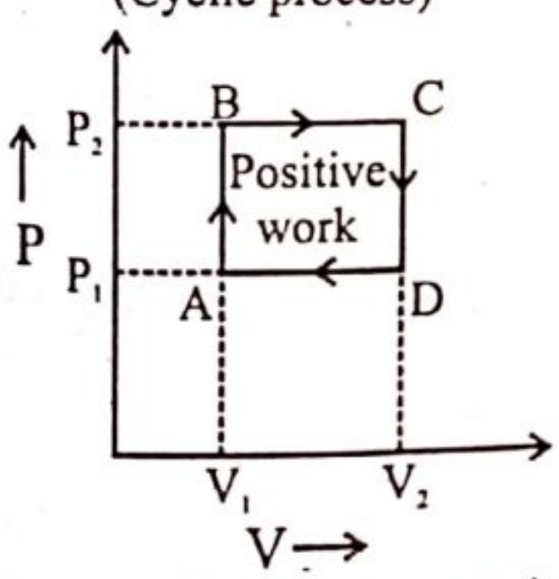
Rapid escape of air from automobile tyre is an example of adiabatic expansion.

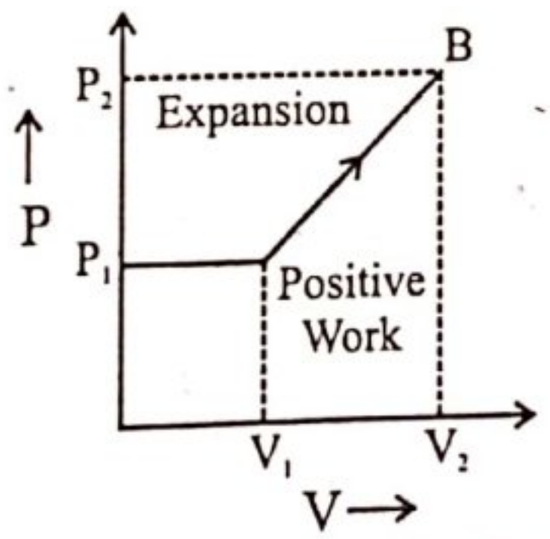
WORK

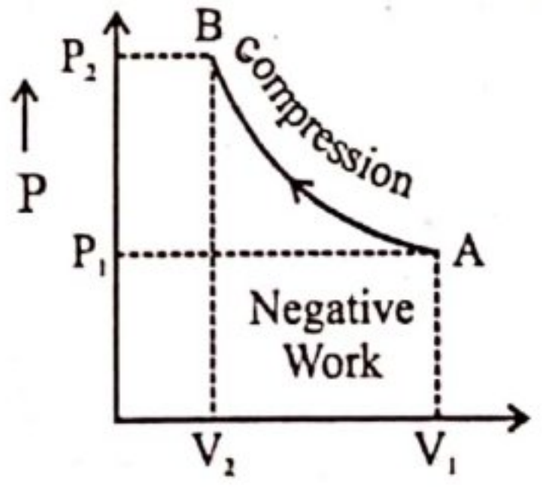
Work can be defined as the energy that is transferred one body to the other owing to a force that acts between them. The amount of work done by a system as it expands or contracts is given by: $W = P\Delta V$

- Work is taken to be positive if the system expands against some external force. Work is taken to be negative if the system contracts because of some external force exerted by the surroundings.
- **Work calculation by indicator-diagram method:** It is positive if volume increases and negative if volume decreases.

(Cyclic process)

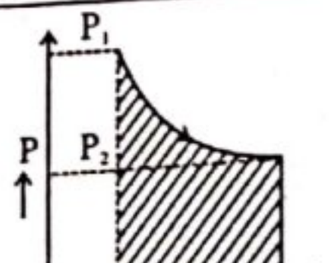
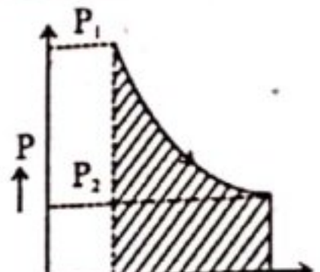
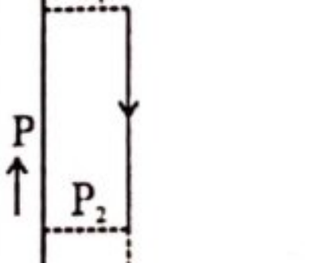
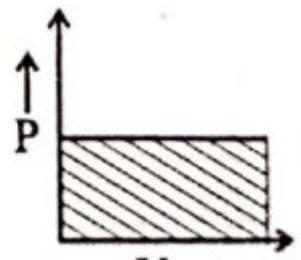






- If area under PV-diagram is traced in clockwise direction the work done will be positive (expansion) and will be negative (during compression) if the area is traced in anticlockwise direction.

Comparison of Different Thermo Dynamical Processes

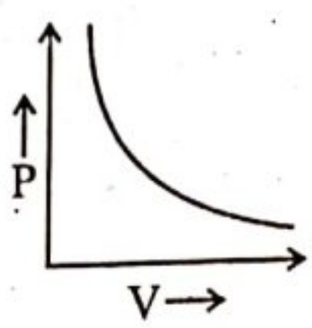
Sr. No.	Property	Isothermal	Adiabatic	Isometric (Isochoric)	Isobaric
1.	Condition	T=constant, $\Delta T=0$, $\Delta U=0$	Q=constant, $\Delta Q=0$	V=constant, $\Delta V=0$, $\Delta W=0$	P=constant, $\Delta P=0$
2.	Form of first Law	$\Delta Q=0+\Delta W$ $\Delta W=P\Delta V$	$0=\Delta U+\Delta W$ $\Delta W=-\Delta U$	$\Delta Q=\Delta U+0$, $\Delta U=n\,C_v\Delta T$	$\Delta Q=\Delta U+\Delta W$ $=nC_p\Delta T$
3.	P.V Diagram				

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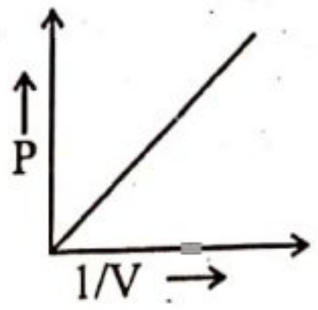
4.	Equation of state	PV=constant	PV^{γ}=constant	$\frac{P}{T}$ = constant	$\frac{V}{T}$ = constant
5.	Specific Heat	$c = \infty$	$c = 0$	$c = C_v$	$c = C_p$
6.	Slope of P.V curve	$\frac{\Delta P}{\Delta V} = -\frac{P}{V}$	$\frac{\Delta P}{\Delta V} = -\gamma\frac{P}{V}$	$\frac{\Delta P}{\Delta V} = \infty$	$\frac{\Delta P}{\Delta V} = 0$
7.	Elasticity	$E_T = P$	$E = \gamma P$	$E = \infty$	$E = 0$
8.	Operating condition for process	Process should be completed very slowly	Process is to be completed rapidly and the system should be surrounded by thermally insulated medium	----	----
9.	Example	(i) Isothermal expansion of ideal gas, (ii) Conversion of ice at 0°C to water of 0°C	(i) Burst of air tube (ii) Propagation of sound in air (iii) Refrigeration	(i) To supply heat at constant volume, (ii)Atmospheric changes, (iii)Explosion in gases	(i) Melting of ice, (ii) Boiling of water

Different Thermodynamic and Relative Processes

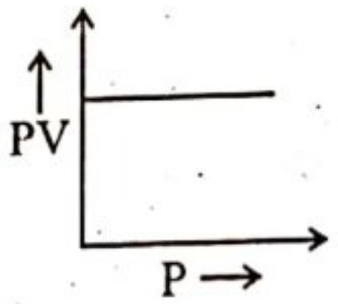
Thermodynamic processes



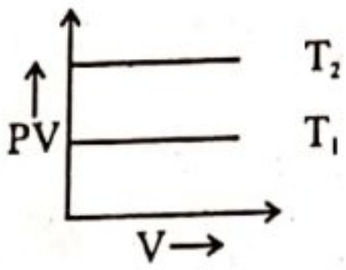
P–Vcurve

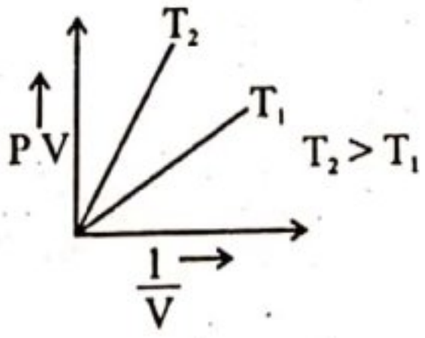


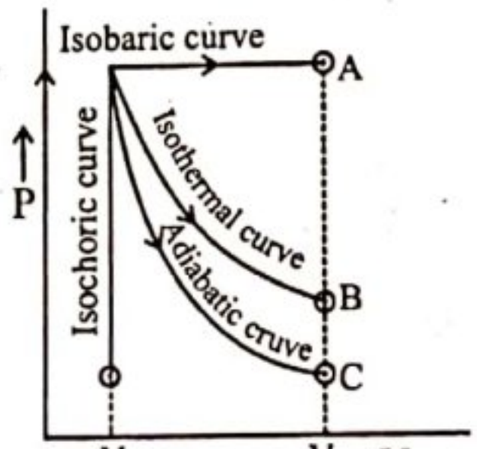
P– $\frac{1}{V}$ curve



P and PV curve







C_P is greater in value than C_V

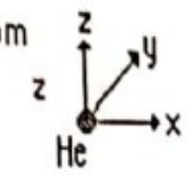
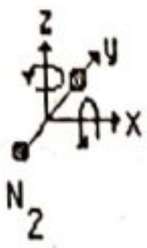
- $\Delta Q_V = n C_V \Delta T$ (Heat supplied at constant volume).
- $\Delta Q_P = n C_p \Delta T$ (Heat supplied at constant pressure).
- $C_P - C_V = R$.
- $\frac{C_P}{C_V} = \gamma$

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REVERSIBLE AND IRREVERSIBLE PROCESSES

- Sequence of processes carried out in such a manner that the values of thermodynamic variables are retrieved at the end of processes then this process is called reversible process. Otherwise called irreversible.
- Liquefaction, evaporation and compression performed slowly are reversible processes.
- All changes that occur suddenly or involve friction or dissipation of energy through conduction, convection or radiation are irreversible processes.

POINT TO PONDER

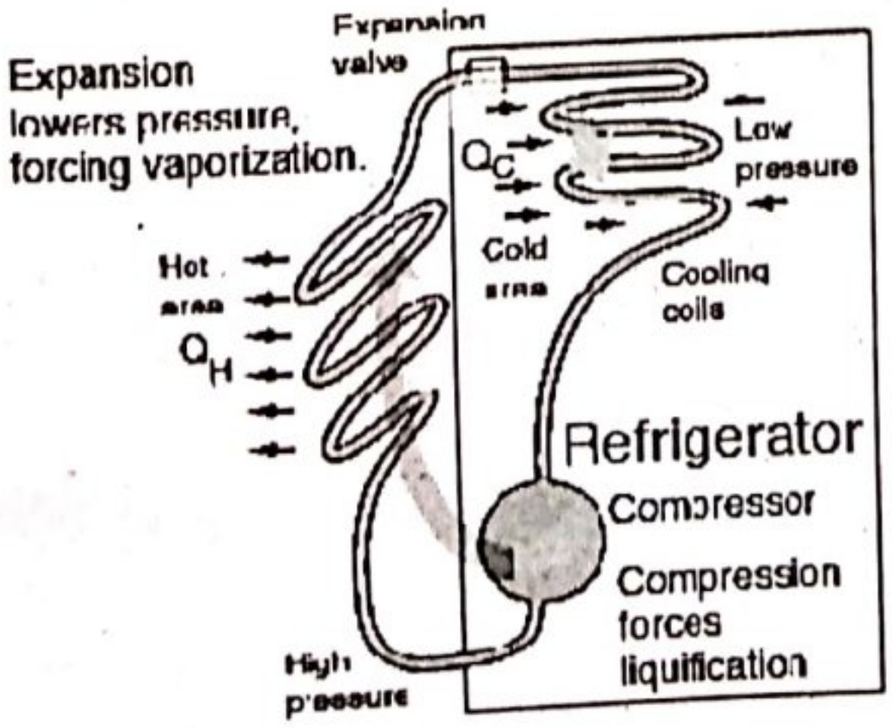
Degrees of freedom		
3		Monoatomic $C_v = \frac{3}{2}R = 12.5 \frac{J}{mol\ K}$
5		Diatomic $C_v = \frac{5}{2}R = 20.8 \frac{J}{mol\ K}$
6		Polyatomic $C_v = \frac{6}{2}R = 24.9 \frac{J}{mol\ K}$

Second Law of Thermodynamics

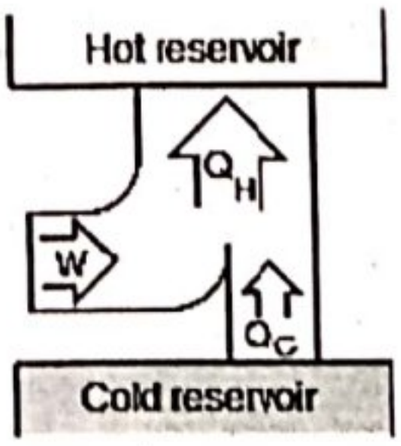
Kelvin Statement: "It is impossible to construct a heat engine which converts all heat energy absorbed from source without having a sink."

Clausius's Statement: "It is impossible to transfer heat from cold to hot region without expenditure of external energy."

Refrigerator: A refrigerator is a heat engine in which work is done on a refrigerant substance in order to collect heat from a cold region and exhaust it in a higher temperature region, thereby further cooling the cold region.



All real refrigerators require work to get heat to flow from a cold area to a warmer area.



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HEAT ENGINE

Heat engine is a thermodynamic device, which converts heat energy into mechanical energy.

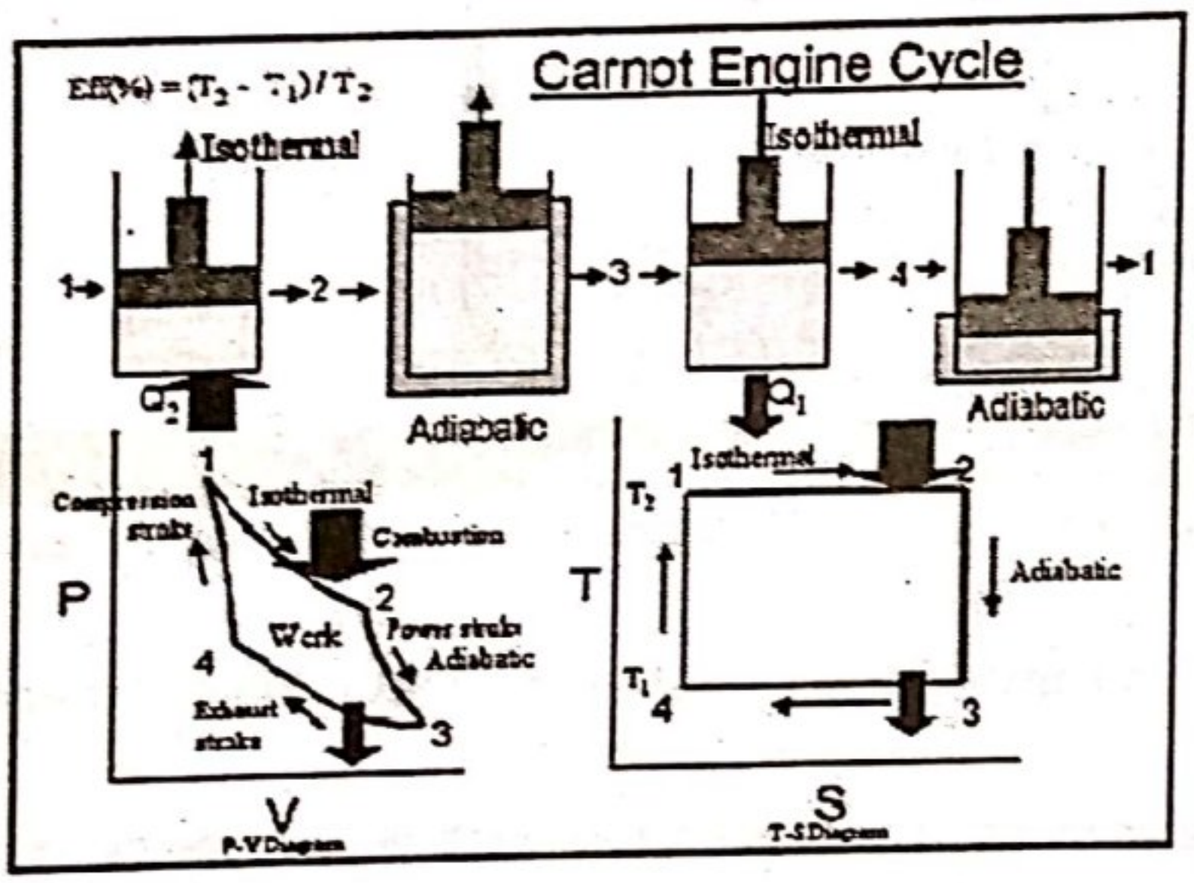
- There exists no perfect heat engine.
- Heat engine always operates in a cycle.
- Cycle means set of changes, which bring a system to its initial state.

CARNOT HEAT ENGINE

- Sadi Carnot proposed it in 1840. (ideal Engine).
- Carnot heat engine has maximum efficiency, but not 100%. $\eta_c = \left(1 - \frac{T_2}{T_1}\right) \times 100$
- Carnot cycle consists of following processes;

(i) Isothermal expansion (ii) Adiabatic expansion

(iii) Isothermal compression (iv) Adiabatic compression



POINT TO PONDER

The area under the PV graph gives us the work done by the engine.

Following things should be kept in mind about efficiency of Carnot engine: -

(i) It depends upon temperature difference between the source and the sink.

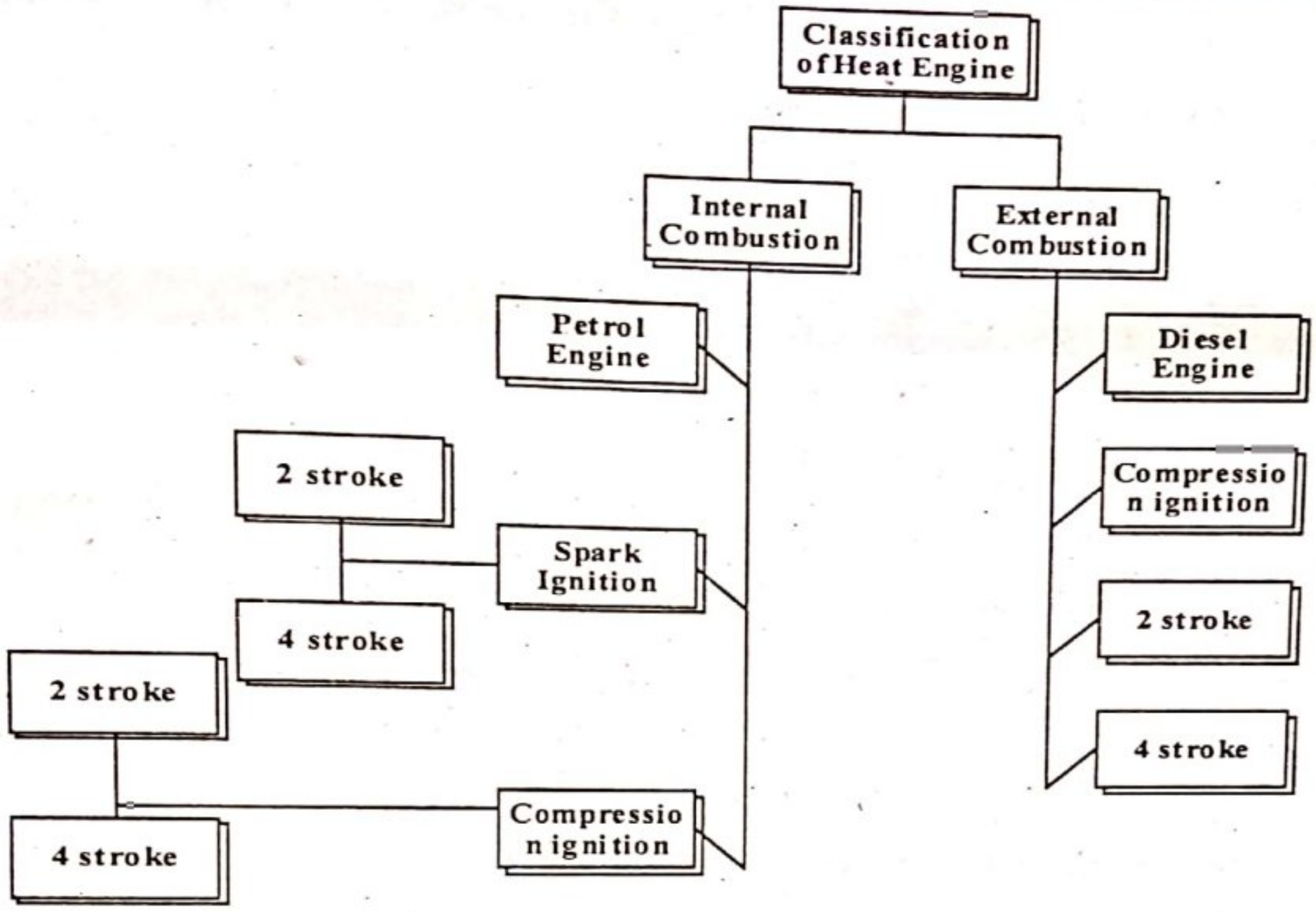
(ii) It is independent of nature working substance

(iii) It is 100% only when $T_2 = 0$ K

(iv) Carnot engine cannot be constructed practically.

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CLASSIFICATION OF HEAT ENGINE

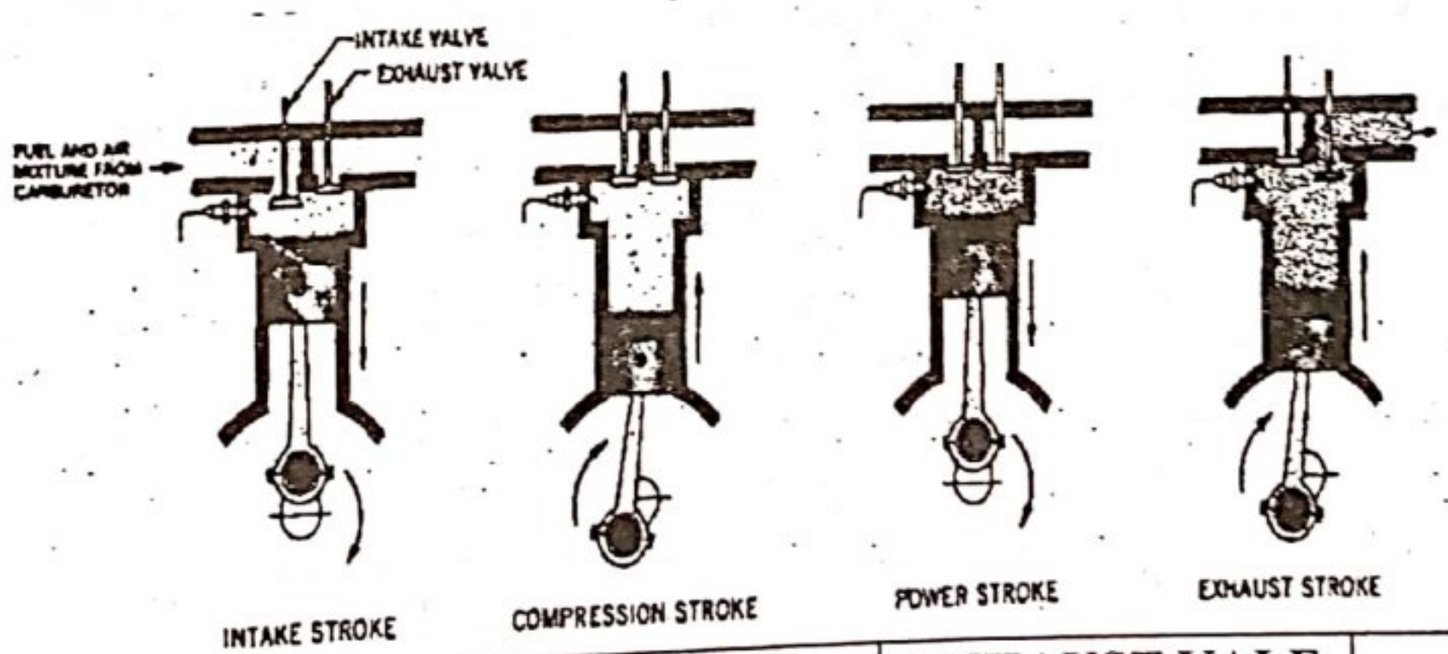


Heat Engine

There are four major parts of every engine.

(i) Cylinder **(ii)** Piston **(iii)** Crank shaft **(iv)** Connecting rod

The piston oscillates within the constraints of the cylinder and this reciprocating movement is converted to rotary motion by the relative movement of crankshaft and connecting rod.



STORKE	DIRECTION	INTAKE VALVE	EXHAUST VALE	GAS
Intake	Down	Open	Closed	Enters
Compression	Up	Closed	Closed	Compressed
Power	Down	Closed	Closed	Burnt
Exhaust	Up	Closed	Open	Expelled

The Four-stroke-cycle principle

PETROL ENGINE

- There are four successive processes in each cycle of a petrol engine.

(i) Charging stroke or intake stroke **(ii)** Compression stroke

(iii) Power stroke **(iv)** Exhaust stroke

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- There is one cylinder in motorbike's engines.
- There usually are four cylinders in cars. Each one fire turn by turn for smooth running of the car.
- Efficiency of petrol engine is about 25% to 30%.
- Diesel engine has no spark plug.
- Efficiency of diesel engine is about 35% to 40%.

ENTROPY

- Degree of **disorderliness** is called statistical entropy.
- Unavailability of heat energy is called thermo entropy.

Law of increase of entropy: "Entropy of a thermodynamic system either remains constant (during reversible process) or it increases (during irreversible process)".

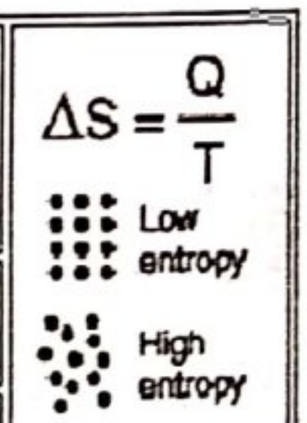
- We can represent change in entropy by following relation given by Clausius.

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

Where ΔS is +ve if heat enters and vice versa.

- Its unit is J K^{-1}.
- Entropy may remain constant for a reversible process.
- Entropy increases for all irreversible processes.

Entropy	A state variable whose change is defined for a reversible process at T where Q is the heat absorbed.
Entropy	A measure of the amount of energy which is unavailable to do work.
Entropy	A measure of the disorder of a system.
Entropy	A measure of the multiplicity of a system. (Point to ponder)



Environmental Crisis as Entropy Crisis

- Entropy is a time arrow.
- Increase of entropy leads to heat death of universe because thermal pollution is an inevitable consequence of 2nd law of thermodynamics.
- Environmental crisis is an entropy or disorder crisis resulting from our futile efforts to ignore the 2nd law of thermodynamics

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BOOK-II

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12 CHAPTER ELECTROSTATICS

INTRODUCTION

- The physics that deals with charges at rest is called electrostatics and that which deals with moving charges is called electrodynamics.
- An electric force is the force, which holds the positive and negative charges that **make up atoms, molecules** and **bodies.**

Charge & Its Relationship with Friction

- Bodies get charge due to friction.
- During rubbing process, free or atomic electrons gain more energy than work function and get detached thus producing positive charge.
- **Similar charges repel each other while opposite charges attract each other.**
- Excess of electrons **create negative charge** while their **deficiency produces positive** charge in an object.
- SI unit of charge is coulomb. It is defined as:
  "If force between two equal and opposite charges placed in a vacuum 1m apart is $9x10^9$N then each of them bear 1C charge."

  OR

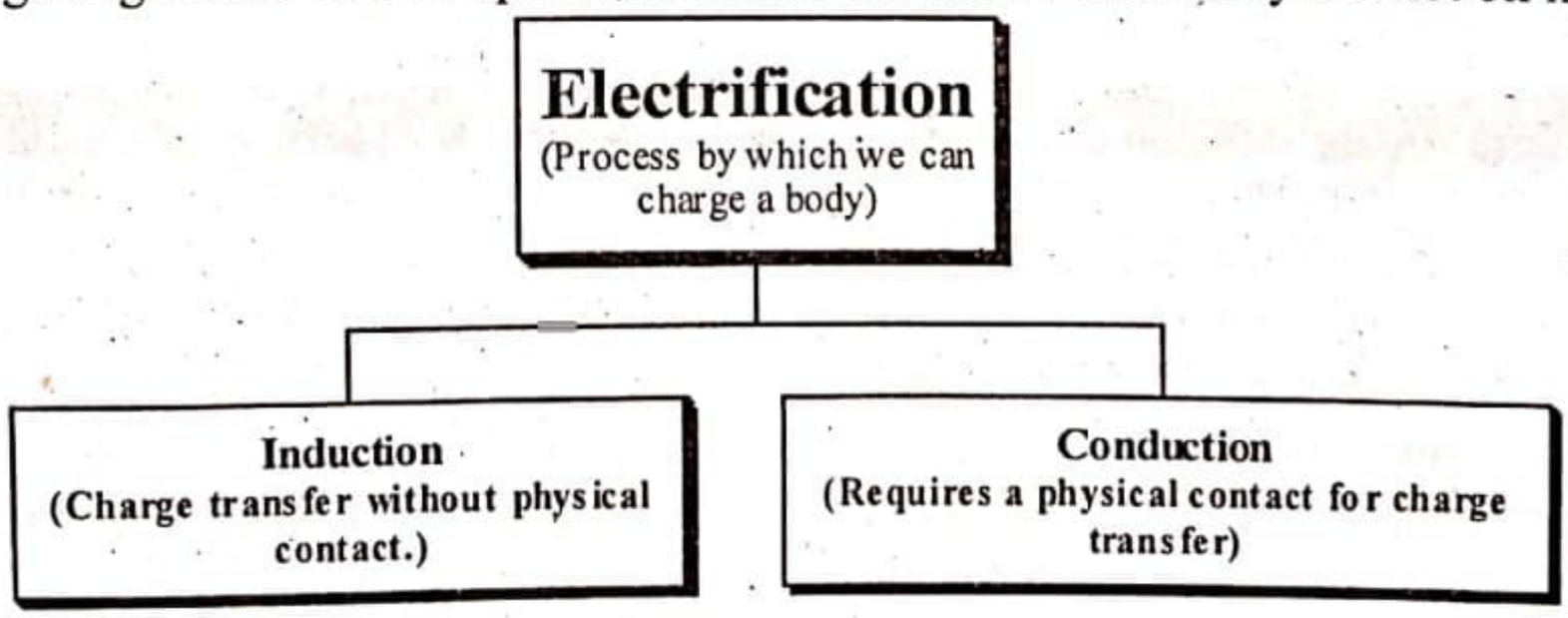
  "If 1A current flows in 1 s then charge will be IC."

  OR

  " Charge of $6.25x10^{18}$ electrons is 1coulomb."
- Charge is a **conserved quantity** as well as **quantized.**

(i) Charge per unit area ($\Delta Q/\Delta A$) is called **surface charge density.**
(ii) Charge per unit volume ($\Delta Q/\Delta V$) is called **volume charge density.**
(iii) Charge per unit length ($\Delta Q/\Delta L$) of straight conductor is called **linear charge** density.

- When charged particle is subjected to electric field, then its acceleration is qE/m.
- When charge is given to hollow sphere, it resides on outer surface only but not on inner surface.



Electrical Forces

- Electrical forces are repulsive and attractive in nature depending upon likeness or unlikeness of the charges respectively.
- Interaction of field explains force.
- Origin of electric force is provided by quantum electrodynamics.
- Coulomb used an apparatus known as **torsional balance** for experimental measurement of electrical force operating between two point charges.

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Coulomb's Law

Coulomb found that electrical force between two point charges is-

(i) Directly proportional to product of magnitude of the charges.

(ii) Inversely proportional to square of distance between them

(iii) Act along line joining them.

Mathematically,

$$F_e = k\, q_1 q_2 / r^2$$

Where $k = 9 \times 10^9$ N-m^2/C^2

In vacuum, and using S.I units.

$$k = 1/4\pi\varepsilon_o$$

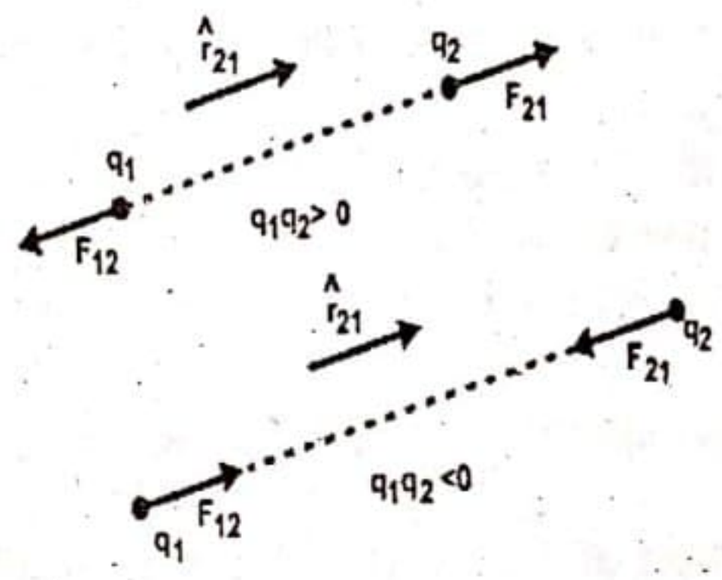
Where $\in_0$ is permittivity of free space.

$$\varepsilon_o = 8.85 \times 10^{-12}\ C^2/N\text{-}m^2$$

POINT TO PONDER

Two bodies having charge, very small in size as compared with the distance between them acts as point charges.

- $\vec{F}_{12} = -\vec{F}_{21}$ Shows that electrical forces form an action-reaction pair.
- Coulomb's law obeys **inverse square law.**
- When charges are placed in medium other than air, then force reduces by a factor $\in_r$ known as **relative permittivity** of medium.



$$F' = \left(\frac{1}{\varepsilon_r}\right)F$$

$$F' = \left(\frac{F}{\varepsilon_r}\right)$$

- In terms of electrical force, $\in_r$ can be given as; $\varepsilon_r = \left(\frac{F}{F'}\right)$

It means that relative permittivity is ratio between electrical force between two point charges, when placed in air or vacuum to the electric force between them when placed in medium other than vacuum.

- ε_r, the relative permittivity is unit less quantity.

ELECTRIC FIELD

Electric field is a vector quantity.

- It is intrinsic property of "charge" to have electric field around it.
- Two theories has been put forward to explain electric field -

(i) Action at a distance (Newton's view)

(ii) Field theory (Faraday's view)

- Action-at-distance has been rejected experimentally while field theory is a convincing view.
- For infinite extent, field is uniform all over.

For **finite extent**, field is **non-uniform at ends**. (Fringing Field)

ELECTRIC INTENSITY

- Electric intensity is given as; $\mathbf{E = F/q_o}$

Where q_o is a test charge. It is defined as the force per unit positive charge.

- In vector form $\vec{E} = k\frac{q}{r^2}\hat{r}$ for a point charge.
- SI unit of E is N/C and V/m

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ELECTRIC LINES OF FORCE

Definition

The path followed by a tiny positive charge in an electric field is called line of force.

Electric lines of force are imaginary lines **starting** from positive charge and **ending** on negative charge.

Some of important properties are given below;

(i) Originate from positive charge.
(ii) End on negative charge.
(iii) Do not intersect
(iv) Contract longitudinally.
(v) Repel transversely.
(vi) No electric line is present inside the conductor.
(vii) Tangent drawn to electric lines gives the direction of electric intensity
(viii) Electric field is stronger where the electric lines are **closely packed**

XEROGRAPHY (PHOTOCOPIER)

- "Xeros" means **"dry"**, "graphy" means, **"writing".**
- The lamp transfers the image of document as bright and dark spots on **drum** (core of the Machine).
- Drum is an aluminum cylinder coated with selenium. Selenium is a LDR (Light dependent resistor). It retains positive charge in dark.
- Positive charge document image is created on the drum.
- Toner is given negative charge and is sprayed over the drum.
- The image is then transferred on paper and is settled by the heated pressure rollers on the paper.

INKJECT PRINTERS

- It works on the thin stream of ink ejected from a nozzle at high speed.
- It passes through two electrical components. **Charging electrode** and **deflection plates.**
- Charging electrode gives a net charge to the stream controlled by instructions from computers.
- The uncharged drops pass without deflection through deflection plates and strike the paper while charged drops are directed to gutter.

ELECTRIC FLUX

Electric flux is the number of electric lines of force passing perpendicular through certain area.

- Mathematically electric flux is defined as;
  $\phi_e = \vec{E} \cdot \vec{A} = EA\cos\theta$ provided $\vec{E}$ is uniform on flat surface represented by $\vec{A}$.
- It is a scalar quantity.
- $\phi_{max} = EA$ when $\theta = 0°$ (surface is $\perp$ to E)
  $\phi_{min} = 0$ when $\theta = 90°$ (surface is $\parallel$ to E)
- If no. of flux lines leaving a closed surface is greater than no. of flux lines entering, then surface contains source or positive charge.
- If no. of flux lines leaving a closed surface is less than no. of flux lines entering it, then surface contains sink or negative charge.
- If no. of flux lines entering is equal to no. of flux line leaving, then surface contain neither sink nor source.

POINT TO PONDER

Electric flux depends upon charge and medium not on shape of the closed surface.

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Flux through Closed Surface

- Flux through closed surface is;

$$\phi_e = Q/\varepsilon_o$$

It shows that flux through closed surface is independent of **location** of charges enclosed by it and **shape** of closed surface.

GAUSS'S LAW

"The flux through a closed surface is $\left(\frac{1}{\varepsilon_o}\right)$ times the total charge enclosed in it".

$$\phi_{total} = \left(\frac{1}{\varepsilon_o}\right) Q$$

Gauss's Law is applied to calculate electric intensity. For this purpose an imaginary closed surfaced called Gaussian surface is considered which must pass through the point at which the electric intensity is to be evaluated.

POINT TO PONDER

Any apparatus placed within a metal enclosure is shielded from electric fields. Why?

Applications

(i) Electric intensity inside a hollow but uniformly charged sphere is zero. $\mathbf{E} = 0$

(ii) Electric intensity due to **infinite sheet of charge** is given as; $\overline{E} = \frac{\sigma}{2\varepsilon_o}\hat{r}$

(iii) Electric intensity between **two equal but oppositely charged** plates is given as. $\overline{E} = \frac{\sigma}{\varepsilon_o}\hat{r}$

ELECTRICAL POTENTIAL OR POTENTIAL DIFFERENCE

Electric potential difference between two points is defined as:
"Work done per unit positive charge in moving it against electric field with uniform velocity. i.e. keeping the charge in electrostatic equilibrium."

$$\Delta V = \frac{W_{A\to B}}{q_o}$$

- It can be given in terms of potential energy as

$$\Delta V = \frac{\Delta U}{q_o} \qquad \because W_{A\to B} = \Delta U = \text{electrostatic P.E}$$

- SI unit of potential difference is volt.
"If 1J of work is done on one coulomb charge between two points keeping the equilibrium, the potential difference is 1V"

$$\mathbf{1V = 1J/1C}$$

POINT TO PONDER

We can relate electric potential difference and electric field intensity by following relation: $E = -\frac{\Delta V}{\Delta r}$

Where negative shows that E is along decreasing potential N/C is equal to V/m. It means that

(i) We can call 'E' potential gradient because it represents the maximum rate of change of potential difference w.r.t displacement.

(ii) SI unit of E (N/C) is equivalent to V/m. $\frac{1N}{1C} = \frac{1V}{1m}$

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- **Absolute electric potential** at a distance 'r' from source is given as;

$$V_{(r)} = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$$

- **Absolute potential** at a point due to collection of point charges is given as;

$$V = \frac{1}{4\pi\varepsilon_o}\sum_{i=1}^{n}\frac{q_i}{r_i}$$

- **ECG** records the voltage between points on human skin generated by electrical process in the heart while EEG records that by brain.

EQUIPOTENTIAL SURFACES

Definition

The surface on which electric potential is same at each of its points is called equipotential surface.

Example

Surface of the charged hollow sphere containing point charge at its center

Characteristics of Equipotential Surfaces

(i) They do not intersect.
(ii) Potential difference between two **points on equipotential surface** is zero.
(iii) No work is done to move a point charge on an equipotential surface.
(iv) Work is done when point charge is moved from one equipotential surface to another.

ELECTRON VOLT

Definition

The amount of energy acquired or lost by an electron as it traverses a potential difference of one volt.

- $1eV = 1.6\times10^{-19}J$ and $1J = 6.25\times10^{18}$ eV.
- It is the unit of energy specially used for atomic particles.

COMPARISON OF GRAVITATIONAL AND ELECTROSTATIC FORCES

Particulars	Gravitational force	Electrostatic force
Formula	$F_g = Gm_1m_2/r^2$	$F_e = \frac{1}{4\pi\varepsilon_o}\frac{q_1q_2}{r^2}$
Range	Infinite	infinite
Symbol of constant	G	$k = \frac{1}{4\pi\varepsilon_o}$
Value of constant	Very small	Fairly large
Nature	Always attractive	Attractive or repulsive
Dependence	Medium independent	Medium dependent
Relative strength	Weak: can be felt with massive object	Strong at close range

MILLIKAN'S METHOD FOR ELECTRON'S CHARGE

- Atomizer sprays oil droplets
- The droplet between the two plates could be suspended in air if the gravitational force $\mathbf{F_g = mg}$ acting downward on the droplet is equal to the electrical force $\mathbf{F_e = qE}$ acting upward. $\mathbf{qE = mg}$

and $E = \frac{V}{d}$, $\Rightarrow$ $q = \frac{mgd}{V}$

- The terminal velocity is determined by timing the fall of the droplet over a measured distance. Minimum quantum charge is of electron i.e. $1.6\times10^{-19}C$

CAPACITOR & CAPACITANCE

- Capacitor is a device used for **storing electric charge** and electrical energy.
- Charge stored by capacitor is given as; $\mathbf{Q = CV}$
  Where C is **capacitance of** capacitor
- **Capacitance is defined as:** Ability of a capacitor to store charge. **OR**

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"The ratio of charge stored to the potential difference between plates of capacitor."

Mathematically, $C = \frac{Q}{V}$

- SI unit of capacitance is **farad.**
- **1 farad** is defined as;
  The capacitance of a capacitor is one farad if a charge of one coulomb, given to one of the plates of a parallel plate capacitor, produces a potential difference of one volt between them.

$$1F = \frac{1C}{1V}$$

- Capacitance of parallel plate capacitor with air between its plates is given as; $C_{vac} = \varepsilon_o \frac{A}{d}$

The above expression shows that:-

- As we increase the area of plate the capacitance will increase.
- Decreasing the distance between plates will increase the capacitance.
- Introducing a dielectric between the plates will increase the capacitance of the capacitor.
- Capacitance of an isolated charge sphere of radius R is $C = 4\pi \in_o R$.
- Capacitance of a parallel plate capacitor with dielectric between its plate is given as;

$$C_{med} = \varepsilon_r \varepsilon_o \frac{A}{d} = \varepsilon_r C_{vac} \qquad \text{so} \qquad C_{med} > C_{vac}$$

Dielectric Co-Efficient or Dielectric Constant

Definition

The ratio of the capacitance of a parallel plate capacitor with an insulating substance as medium between the plates to its capacitance with vacuum (or air) as medium between them.

$$\varepsilon_r = \frac{C_{med}}{C_{vac}}$$

- Charging of capacitor is due to electrostatic induction phenomenon.
- Old name of capacitor is condenser.

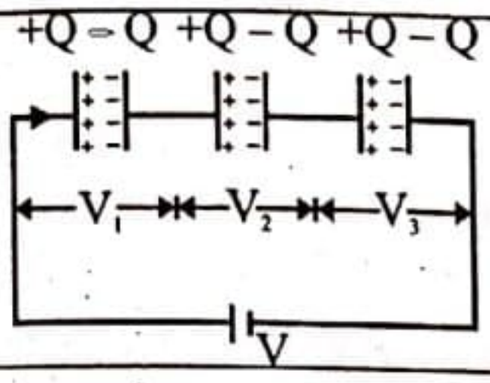
Types of Capacitor

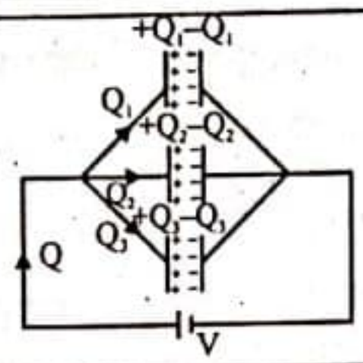
(i) Parallel plate capacitor **(ii)** Spherical capacitor **(iii)** Miniature capacitor
(iv) Tubular capacitor **(v)** Paper capacitor **(vi)** Electrolytic capacitor
(vii) Variable capacitor

COMBINATIONS OF CAPACITORS

SERIES GROUPING	PARALLEL GROUPING
• Capacitors are said to be connected in series between two points when we can proceed from one point to the other only through one path. **OR** • In series grouping charge on each capacitor remains same and equals to the main charge supplied by the battery but potential difference across them may or may not be same.	• The capacitors are said to be connected in parallel between any two points if we proceed from one point to the other along different paths. **OR** • In parallel grouping potential difference across each capacitor remains same and equal to the applied potential difference while charge on them may or may not be same.
• Charge on each capacitor remains same and equals to the main charge supplied by the battery. $V = V_1 + V_2 + V_3$	• Potential difference across each capacitor remains same and equal to the applied potential difference $Q = Q_1 + Q_2 + Q_3$

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- Equivalent capacitance

$$\frac{1}{C_{eq}}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3} \text{ or } \frac{1}{C_{eq}}=\left(C_1^{-1}+C_2^{-1}+C_3^{-1}\right)$$

$$C_{eq}=C_1+C_2+C_3$$

- In series combination potential difference and energy distribution is in the reverse ratio of capacitance, i.e., $V \propto \frac{1}{C}$ and $P.E \propto \frac{1}{C}$

- In parallel combination charge and energy distributes in the ratio of capacitance

i.e. $Q \propto C$ and $P.E \propto C$

- If two capacitors having capacitance C_1 and C_2 are connected in series then

$$C_{eq}=\frac{C_1C_2}{C_1+C_2}$$

- If two capacitors having capacitance C_1 and C_2 are connected in series then

$$C_{eq}=C_1+C_2$$

- If n identical capacitors each having capacitances C are connected in series with supplied voltage V then equivalent capacitance

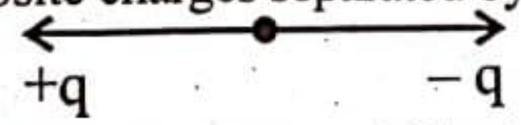
$$C_{eq}=\frac{C}{n}$$

- If n identical capacitors are connected in parallel $C_{eq}=nC$

ELECTRIC POLARIZATION

Polarization is a phenomenon of appearance of opposite charges on surface of a material subjected to **electric field.**

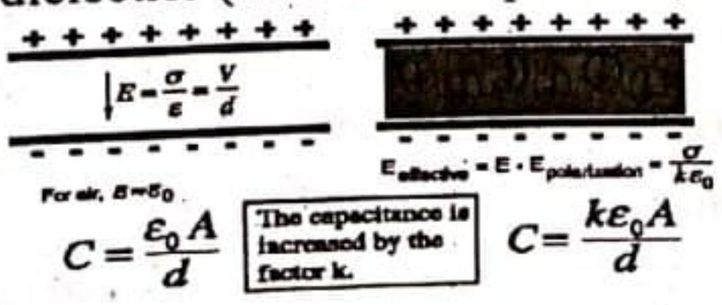
- Polarization charges are called induced charges
- Dipole is a set of two equal and opposite charges separated by a small distance 'r.'



- Some substance are polar i.e. they have **permanent dipoles** e.g. in NaCl, the end with **Na** ion is **positive** while that with **Cl** ion is **negative.**
- Some substances are **non-polar** i.e. they do not have **permanent dipoles** e.g. plastic. They become polarized **temporarily** when subjected to **external field.**
- Polar molecules experience torque when subjected to uniform electric field but zero net force. In non-uniform electric field it **also experiences net force** in addition **to torque.**

DIELECTRICS

- Dielectrics are **non-polar insulators.**
- Polarized dielectrics produce electric field opposite to the applied electric field.
- Molecular view of a polarized dielectric (in case of capacitors) is shown below;



; $k = \varepsilon_r$

It shows that a **static equilibrium** exists within the dielectric.

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Effect of Dielectrics on Various Electrical Quantities

$F' = F / \varepsilon_r$ (decreases)

$E' = E / \varepsilon_r$ (decreases)

$V' = V / \varepsilon_r$ (decreases)

$C' = C \varepsilon_r$ (increases)

POINT TO PONDER

Value of ε_r for all dielectrics is greater than 1 except for air

Effect of Polarization on Capacitance

- The electric polarization of dielectric increases the capacitance.
- The electrons in the dielectric (insulator) remain bounded to their respective atoms. They are just displaced from their normal positions.
- The molecules of the dielectric under the action of electric field become diploes and dielectric is polarized.
- As $E = \sigma/\varepsilon_o$, so electric field between capacitor plates decreases due to **polarization of dielectric.**
- Decrease in E decreases the **potential difference** because $V = Ed$.
- As a result capacitance increases

ENERGY STORED IN A CAPACITOR

- Charge on the plate of capacitor **possesses electrical potential energy** because of the work done to deposit the charge on the plates.
- $P.E = \frac{1}{2}qV$

  Energy in capacitor $= \frac{1}{2}CV^2 = \frac{1}{2}\frac{q^2}{C}$
- Energy is stored in electric field between the plates.
- Energy $= \frac{1}{2}\left[\frac{A\varepsilon_r\varepsilon_o}{d}\right][Ed]^2$
- Energy Density =Energy/volume $= \frac{1}{2}\varepsilon_r\varepsilon_o E^2$

POINT TO PONDER

- For D.C, capacitor behaves as open circuit.
- For A.C, capacitor behaves as closed circuit.

CHARGING AND DISCHARGING A CAPACITOR

- D.C supply stores charges on the plate
- A.C supply does not store charge
- Charging and discharging time depends upon product of R & Ç

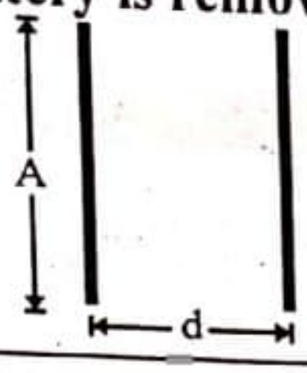
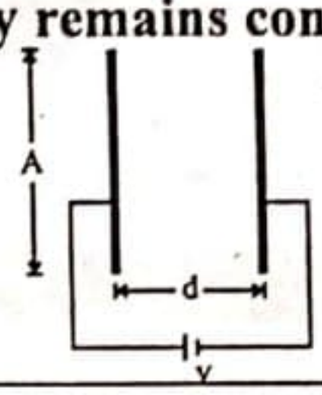
Time Constant

$t = RC$

Its unit is 's' i.e. second.

- Time constant is defined as the time required by a capacitor to charge up to 0.63 times the equilibrium charge on the capacitor.
- Charge reaches its equilibrium value **sooner** when time constant is smaller.
- Windshield wipers of car work by charging and discharging of capacitor.

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A) SEPARATION IS INCREASING		
Quantity	**Battery is removed** 	**Battery remains connected** 
Capacity	Decreases because $C=\frac{1}{d}$ i.e., $C'<C$	Decreases i.e., $C'<C$
Charge	Remains constant because a battery is not present i.e., $q'=q$	Decreases because battery is present i.e., $q'<q$.
Potential difference	Increases because $V=\frac{q}{C}$ $\Rightarrow \quad V\propto\frac{1}{C}$ i.e., $V'>V$	$V'=V$ (since battery maintains the potential difference)
Electric field	Remains constant because $E=\frac{\sigma}{\varepsilon_o}=\frac{q}{A\varepsilon_o}$ i.e., $E'=E$	Decrease because $E=\frac{q}{A\varepsilon_o}$ $\Rightarrow$ $E\propto q$ i.e., $E'<E$
Energy	Increases because $U=\frac{q^2}{2C}$ $\Rightarrow \quad U\propto\frac{1}{C}$ i.e., $U'>U$	Decreases because $U=\frac{1}{2}CV^2$ $\Rightarrow$ $U\propto C$ i.e., $U'<U$

B) SEPARATION IS DECREASING		
Quantity	**Battery is removed**	**Battery remains connected**
Capacity	Increases because $C=\frac{1}{d}$ i.e., $C'>C$	Increases i.e., $C'>C$
Charge	Remains constant because battery is not present i.e., $q'=q$	Increase because battery is present i.e., $q'>q$. Remaining charge $(q'-q)$ supplied from the battery.
Potential difference	Decreases because $V=q/C$ $\Rightarrow \quad V\propto\frac{1}{C}$ i.e., $V'<V$	$V'=V$ (since battery maintains the potential difference)
Electric field	Remains constant because $E=\frac{\sigma}{\varepsilon_o}=\frac{q}{A\varepsilon_o}$ i.e., $E'=E$	Increases because $E=\frac{q}{A\varepsilon_o}$ $\Rightarrow \quad E\propto q$ i.e., $E'>E$
Energy	Decreases because $U=\frac{q^2}{2C}$ $\Rightarrow \quad U\propto\frac{1}{C}$ i.e., $U'<U$	Increases because $U=\frac{1}{2}CV^2$ $\Rightarrow \quad U\propto C$ i.e., $U'>U$

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13 CHAPTER CURRENT ELECTRICITY

ELECTRIC CURRENT

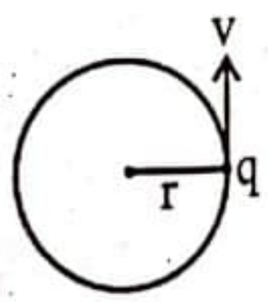
- The rate of flow of charge in a circuit is defined as current.

  i.e. Current $= \frac{\text{Charge}}{\text{Time}}$ or $I = \frac{Q}{t}$ or $Q = It$

- Electric current is equal to charge that flows in one second.
- Electric current is a scalar quantity.
- Unit of current is ampere in M.K.S. system and stat ampere in C.G.S. system.

  and 1 ampere $= 3 \times 10^9$ stat ampere
- 1 ampere = 6.25×10^{18} electrons / second.
- Direction of current is from higher to lower potential. The direction of current is in the direction of flow of positive charge and opposite to the direction of flow of negative charge.
- In metals electric conduction takes place due to flow of free electrons only. But in gases and electrolytes, electric conduction takes place due to flow of both positive and negative ions.

Charge moving in a Circle: If a charged particle of charge q is moving in circular path of radius r with constant speed v and constant frequency f, then Current produced I = fq

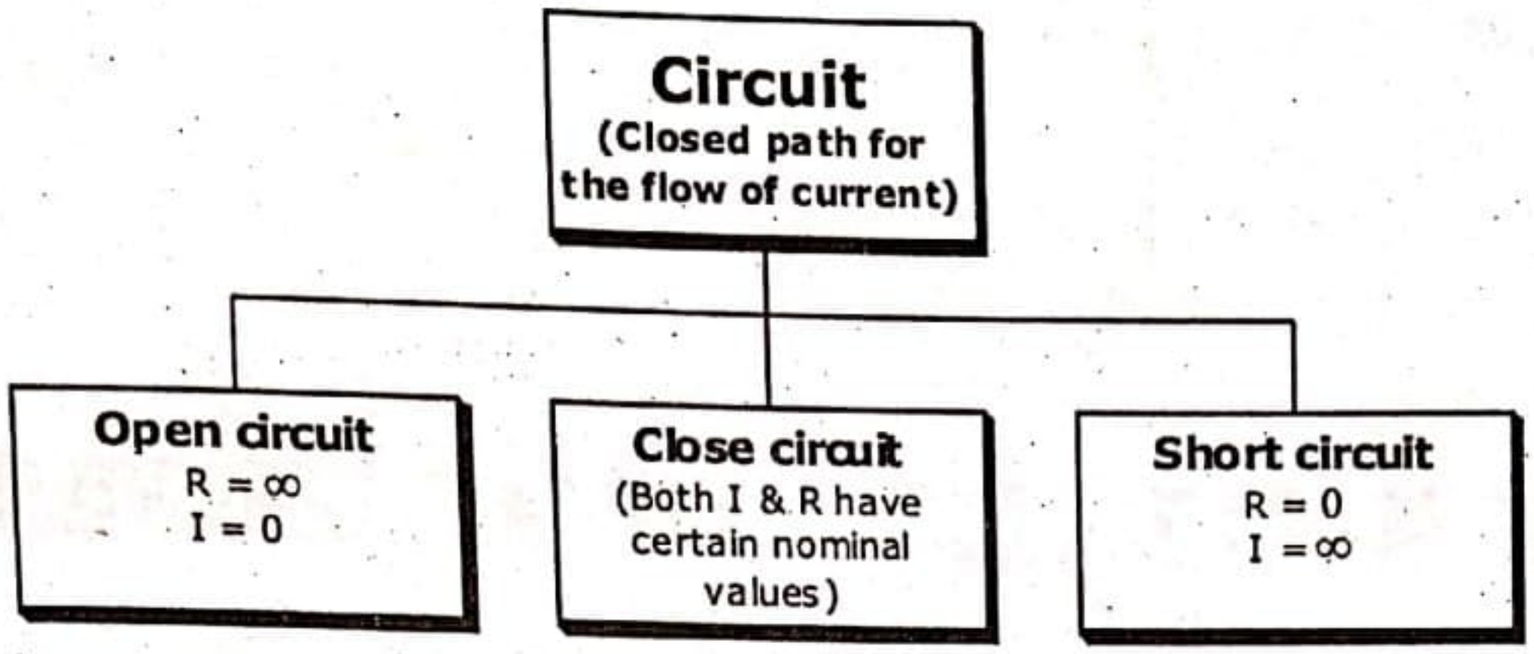


or $I = \frac{vq}{2\pi r}$ $\left(\because \quad f = \frac{v}{2\pi r}\right)$

CONVENTIONAL & ELECTRONIC CURRENT	
Conventional Current	**Electronic Current**
Current due to positive charges is called conventional current	Current due to electrons or negative charges is called electronic current.
It flows from higher to lower potential	It flows from lower to higher potential.
It flows in direction along the direction of field.	It flows in direction against the direction of field.

- both conventional and electronic currents are flowing in a circuit, then total current will be given as; $I_{total} = I_{+ve} + I_{-ve}$
- **Drift velocity (V_d):** It is the average velocity attained by free electrons on applying external electric field. In conductors, $v_d = 10^{-3}\,m\,s^{-1}$
- **Mean free Path (λ):** It is the average distance moved by a free electron between two successive collision with stationary positive ions.
- **Current density (J):** The current flowing per unit normal area of cross section is defined as current density. i.e. $J = \frac{I}{A}\left(amp\,m^{-2}\right)$. Current density is a vector quantity. Its direction is from higher potential to lower potential or its direction is that of the flow of positive charge. $J = nev_d$ where v_d is the drift velocity of electrons.

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- In metallic conductors, the charge carriers are electrons.
- In electrolytes, the charge carriers positive and negative ions.
- In gases, the charge carriers are electrons and positive ions.
- Current is only produced where there is a potential difference
- Due to inelastic collisions of free electrons under the action of potential difference, heat is produced
- A steady current flows when a constant potential difference is maintained.

Source of Current

- It converts some kind of energy into electrical current.
- Cells convert chemical energy into electrical energy.

Name of Device	Notable Feature
Dry Cell	Most commonly used
Primary Cell	Non- rechargeable
Secondary Cell	Rechargeable
Voltaic Cell	Convert chemical into electrical energy
Electric Generator	Convert mechanical into electrical energy
Solar Cell	Convert light into electrical energy
Thermocouple	Convert heat into electrical energy

Effect of Current

- Heating effect i.e. $H = I^2Rt$ such as in heater.
- Magnetic effect such as in transformer, motors etc.
- Chemical effect e.g. electroplating.

OHM'S LAW

The current flowing through a conductor is directly proportional to the potential difference across its ends provided the physical states such as temperature etc. of the conductor remain constant.

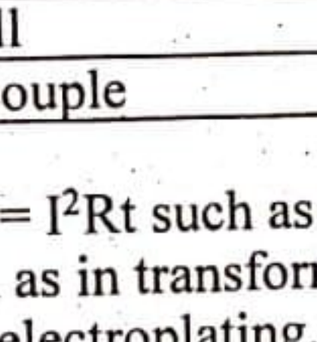
Ohm's law expresses a relation between potential difference and current as given below: **V = IR**

Where R is known as resistance measured in ohms

- Microscopic form of Ohm's law is given as; $J = \sigma E$

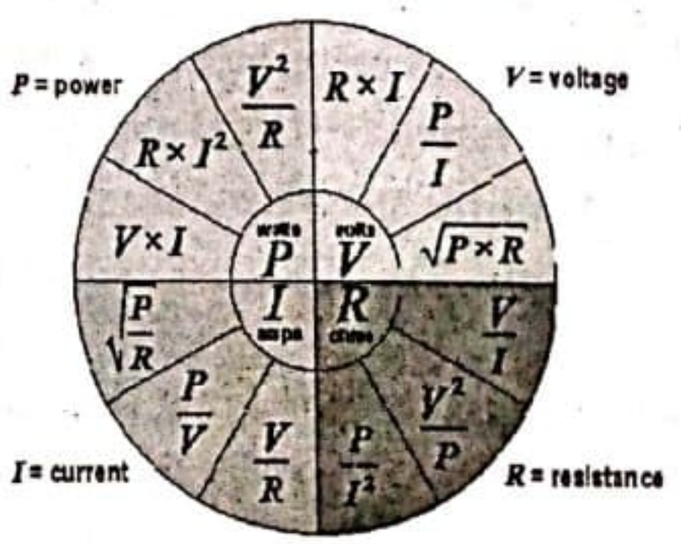
Where σ is conductivity

- The metallic conductor that obeys Ohm's law is called **ohmic conductor.** Its VI graph is a straight line as given below;

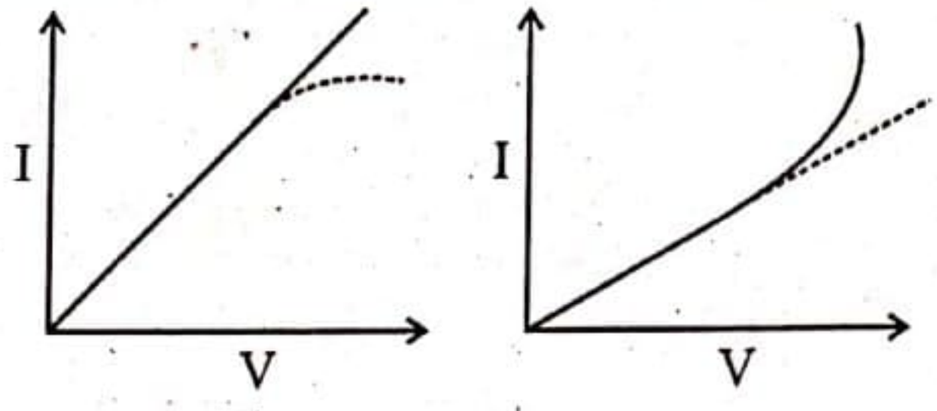


- The conductor that does not obey Ohm's law is called **non-ohmic conductor.** Its VI graph is not a straight line.

POINT TO PONDER



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For conductor For semiconductor

RESISTANCE, RESISTIVITY & CONDUCTIVITY

Resistance

Opposition or hindrance to flow of electron is called **Resistance**

$$R=\frac{V}{I}$$

- Its SI unit is ohm (Ω) that is defined as:
  "If 1V potential difference across a conductor produces 1A current then, resistance will be 1Ω."
- Resistance arises due to collision between **current carriers and vibrating** ions.
- Resistance of conductor depends on following factors:
  (i) $R \propto L$ **(ii)** $R \propto 1/A$
  (iii) $R \propto T$ (except semi-conductors) **(iv)** Nature of material

POINT PONDER

Metallic conductors deviate from their ohmic to non-ohmic behavior when subjected to high potential difference.

- Resistivity is a resistance of 1 m cube of a substance. It is given as;

$$\rho=\frac{RA}{L}$$

Where ρ is called resistivity

- We can say that,

$\rho = R$ if $A = 1m^2$, $L = 1m$

Its SI unit is Ω-m.

- We can say that,
- Reciprocal of resistivity is called conductivity

$$\sigma=\frac{1}{\rho}$$

Its SI unit is $(\Omega\text{-m})^{-1}$

- R increases with rise of temperature because of increase in amplitudes of vibration of ions the collision chance of electrons against ions increases.
- **Conductance = 1/Resistance**
  Its **SI unit** is **mho or siemen.**

Temperature Co-Efficient of Resistance and Resistivity

- Fractional change in resistance per Kelvin change in temperature is called temperature co-efficient of resistance. It is given as;

$$\alpha=\frac{R_t-R_o}{R_o\Delta T}=\frac{\Delta R}{R_o\Delta T} \quad \text{or} \quad R_T=R_o(1+\alpha\Delta T)$$

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- Fractional change in resistivity per Kelvin change in temperature is called **temperature co-efficient of resistivity**

$$\alpha = \frac{\rho_T - \rho_o}{\rho_o \Delta T} = \frac{\Delta\rho}{\rho_o \Delta T} \quad \text{or} \quad \rho_T = \rho_o (1 + \alpha \Delta T)$$

- SI unit of co-efficient of resistance or resistivity is K^{-1}
- Temperature co-efficient of conductors is helpful in differentiating them.
- If two conductors (e.g. iron and platinum) have equal resistivity, even then they can be differentiated, by measuring their temperature co-efficient of resistivity.

COMBINATIONS OF RESISTANCES

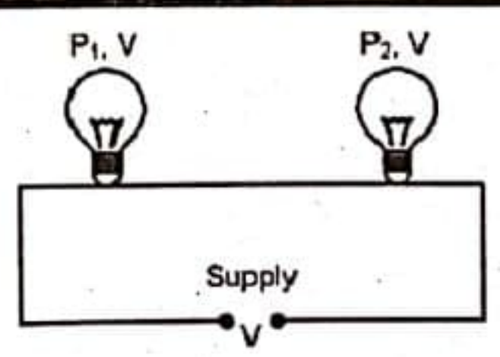
Series combination	Parallel combination
One path for current passage	More than one paths for flow of current
Same current through each component	Different current through each component depending on its resistance
Different potential difference across each component	Same potential difference across each component.
R_{eq} is larger than the largest resistance in the circuit	R_{eq} is smaller than the smallest resistance in the circuit.
$R_{eq} = \sum_{i=1}^{n} Ri$	$\frac{1}{R_{eq}} = \sum_{i=1}^{n} \frac{1}{Ri}$

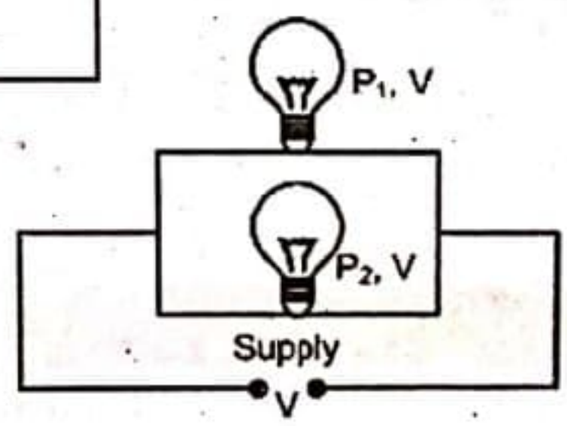
In all combinations of resistors, law of conservation of energy and charge apply.

COMBINATION OF BULBS

Bulbs in Series

- Total power consumed $\frac{1}{P_{total}} = \frac{1}{P_1} + \frac{1}{P_2} + \ldots$
- If 'n' bulbs are identical, $P_{total} = \frac{P}{n}$
- $P_{consumed}$ (Brightness) $\propto V \propto R \propto \frac{1}{P_{rated}}$ i.e. in series combination bulb of lesser wattage will give more bright light and p.d. appeared across it will be more.





Bulbs in Parallel

- Total power consumed
- $P_{total} = P_1 + P_2 + P_3 + \ldots + P_n$
- If 'n' identical bulbs are in parallel $P_{total} = nP$
- $P_{consumed}$ (Brightness) $\propto P_R \propto I \propto 1/R$ i.e. in parallel combination, bulb of greater wattage will give more bright light and more current will pass through it.

Solved Example

Two bulbs are working in parallel order. Bulb A is brighter than bulb B. If R_A and R_B are their resistance respectively then

(A) $R_A > R_B$ (B) $R_A < R_B$ (C) $R_A = R_B$ (D) None of these

Solution

(B) In parallel $P_{consumed} \propto$ Brightness $\propto 1/R$

$P_A > P_B$ (given) $R_A < R_B$

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JOULE THOMSON'S EFFECT & POWER DISSIPATION

- When current flows through conductors, then a part of energy of current carriers is transferred to ions on their way, due to which their amplitudes of vibration increases which result in rise of temperature. The above phenomenon is known as Joule Thomson's effect. Hence electrical energy is wasted that is given as;

$$W = Q\,V$$

$$P = \frac{W}{t} = \frac{QV}{t}$$

$$P = IV$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

Where P represents the power dissipation.

- Heat produced due to power dissipation is given as;

$$H = P \times t$$
$$= I^2 R\,t$$
$$= V\,I\,t$$
$$= V^2 t / R$$

- If 1J electrical energy is dissipated per second, then power dissipated will be 1 watt.

$$1 \text{ watt} = 1J / 1s$$

- Kilowatt-hour is a commercial unit of **electrical energy.** It is defined as:

"When a power of 1kW is maintained through a circuit for 1 hour, then energy dissipated is 1kW h."

$$1 \text{ kW h} = 1000 \text{ W} \times 3600 \text{ sec}$$
$$= 3.6 \times 10^6 \text{ J}$$
$$1 \text{ J} = 2.77 \times 10^{-7} \text{ kW h}$$

EMF

emf of a source is defined as potential difference between its out put terminals when either its internal resistance **is zero or no current is being drawn from it.**

- When charge carriers flow through a conductor, they loose their electrical K.E. In doing work against resistance, loss of energy is compensated by source of **emf at same rate.**
- Every source of emf has its own resistance called **Internal resistance.**
- Smaller is the internal resistance of a battery, better it will be a source of emf
- **Terminal potential** difference is a voltage between out put terminals of a source of emf when current is **drawn from it.**
- We can relate emf (ε), terminal potential (V_t) and internal resistance(r) by the following equation:

$$\frac{\varepsilon}{V_t} = \frac{V_t + Ir}{\varepsilon - Ir}$$

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POINT TO PONDER

There are few relations for comparing V_t and E-

(i) $V_t = \varepsilon$ if $I = 0$ (open circuit)

(ii) $V_t = \varepsilon$ if $r = 0$

(iii) $V_t < \varepsilon$ by a factor I r except when one battery charges the other emf is "cause" & potential difference is its "effect". Maximum power is delivered when r = R

KIRCHHOFF'S LAWS

Kirchhoff's Current Law (KCL)

The sum of all the currents flowing towards a point is equal to the sum of all the currents flowing away from the point.

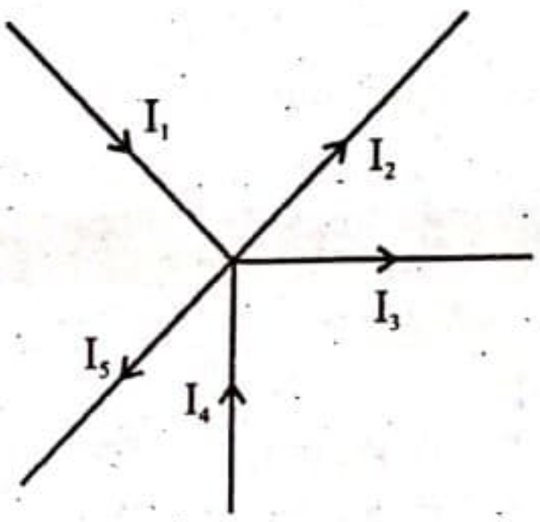
Therefore, $I_1 + I_4 = I_2 + I_3 + I_5$

Hence, $I_1 + I_4 - I_2 - I_3 - I_5 = 0$

Or $\sum I = 0$

(Sum of currents entering a junction = Sum of currents leaving the junction)

This rule is based on the fact that charge cannot be accumulated at any point in a conductor in a steady situation.



Kirchhoff's Voltage Law (KVL)

The algebraic sum of potential changes in a closed circuit is zero.

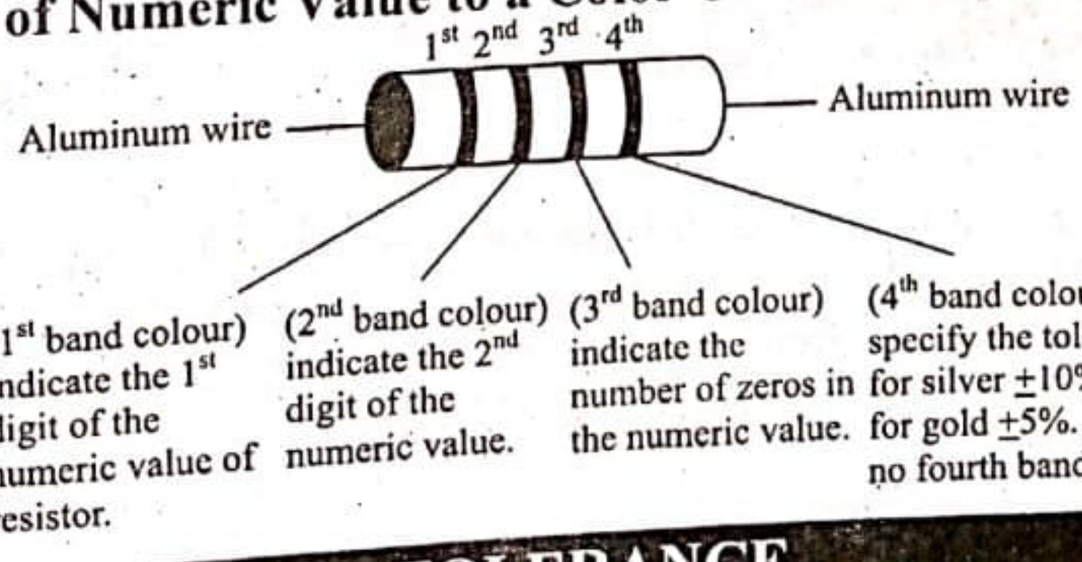
- Loop is a branch of circuit that originates and terminates at the same point.

COLOUR CODE FOR CARBON RESISTORS

B	B	R	O	Y	G	B	V	G	W
O	1	2	3	4	5	6	7	8	9

The resistances are of fixed values but highly temperature dependent.

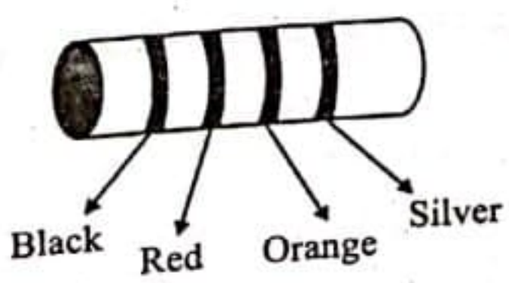
Method of Designation of Numeric Value to a Color Coded Carbon Resistor



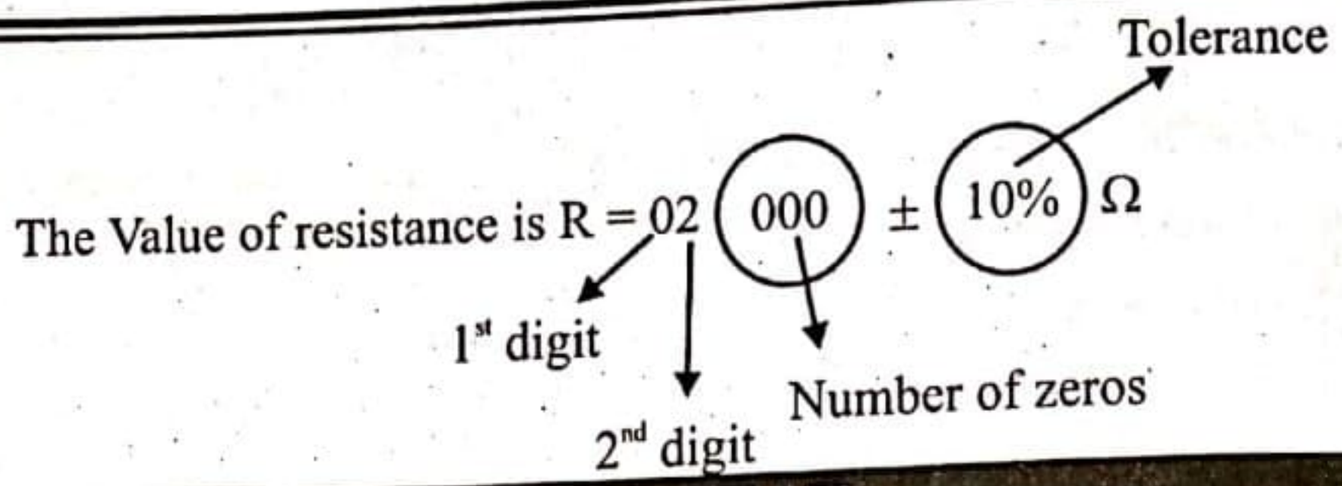
TOLERANCE

By tolerance, we mean the possible variation from the marked value.

For Example



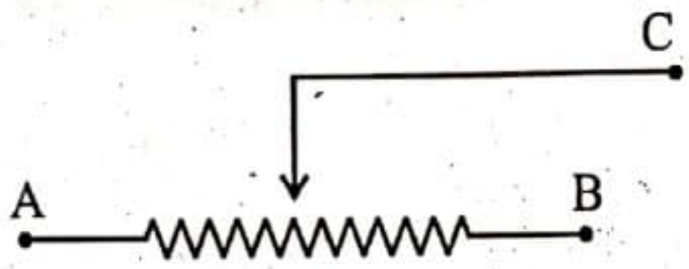
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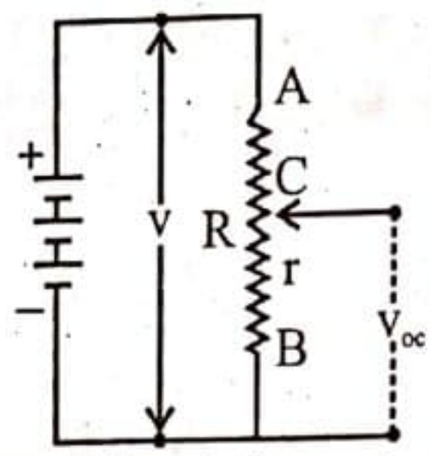


RHEOSTAT

- It is a wire wound variable resistance consisting of bare maganine wire wound over an insulating cylinder.
- It works on the principle that changes in length effects the value of resistor. $R \times \ell$

Symbol in electrical circuits is





Use of rheostat as potential divider

- Rheostat is used as a **variable resistance** as well as **potential divider** just like dimmers in electric fans and volume control knob in radio set.

THERMISTORS

Features

- Non-metallic resistors
- Highly heat sensitive resistor
- Negative temperature coefficient of resistance i.e
- Resistance decreases with increase of temperature
- Thermistors with positive temperature coefficient are also available

POINT TO PONDER

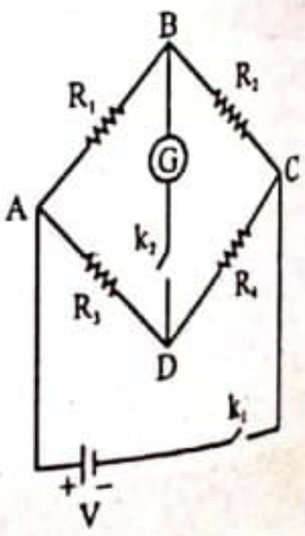
The thermistors with positive temperature coefficients are also available.

Uses

- For very accurate measurement of very low temperature near about 10K or –263°C.
- As heat sensors because it converts changes of temperature into electrical voltage.

WHEATSTONE BRIDGE (W.S.B)

- W.S.B consists of 4 resistances R_1, R_2, R_3 and R_4 connected in loop or mesh of certain pattern.
- W.S.B is an accurate measuring instrument of resistance up to two decimal places.
- WSB is balanced when its galvanometer shows no deflection even when its keys are closed.
- Condition for balanced bridge is that current through galvanometer is zero. Voltage across the terminals of the galvanometer will be equal.



Principle of Whetstone Bridge

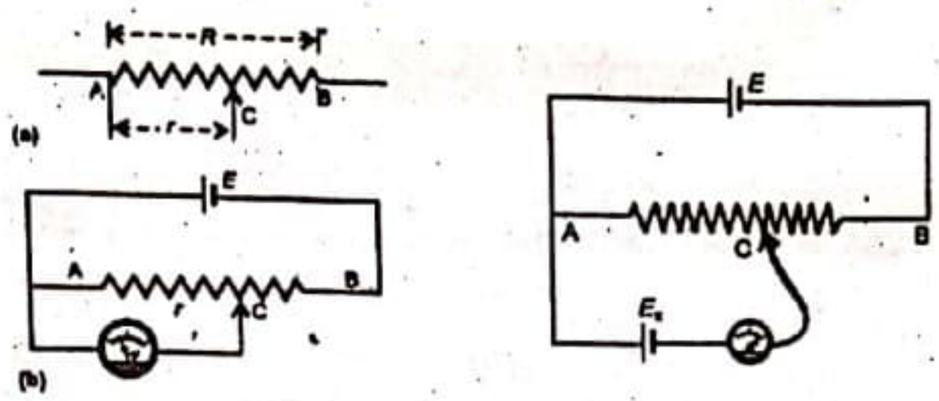
$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

- Unknown resistance is placed at R_3 or R_4.
- Practical form of Whetstone Bridge is **post office box** and **slide Wire Bridge** that is also called Meter Bridge.

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POTENTIOMETER

It is a device which is used to compare and find unknown emf in a circuit without drawing any current from the circuit.



Uses

- Accurate measurement of potential difference
- Measurement of emf of a battery
- Comparing emf's of batteries
- Internal resistance of a cell
- Wire of potentiometer is **4 m long**, made of high resistance wire **(eureka)**

Principle of Potentiometer

Voltage across any length of a wire of uniform area of cross section is directly proportional to its length when a constant **current flows through** it i.e. $V \propto \ell$ and current is **I = E/R**

- The ratio of the emf of two cells is equal to ratio of the **balancing lengths** i.e.

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

Difference between Voltmeter and Potentiometer

VOLTMETER	POTENTIOMETER
Its resistance is high but finite	Its resistance is infinite
It draws some current from source of emf	It does not draw any current from the source of unknown emf
The potential difference measured by it is lesser than the actual potential difference	The potential difference measured by it is equal to actual potential difference
Its sensitivity is low	Its sensitivity is high
It is a versatile instrument	It measures only emf or potential difference
It is based on deflection method	It is based on zero deflection method

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14 CHAPTER ELECTROMAGNETISM

INTRODUCTION

- Study of magnetic properties is called magnetism.
- Study of magnetic properties associated with electricity and the laws relating to them is called electromagnetism.
- Iron ore "magnetite (Fe_3O_4)" was discovered as **early as 600 B.C** from Magnesia, a region in Asia Minor, situated **in modern** Turkey.
- Ore magnet was named **"LODESTONE"** meaning leading stone, having directional property.
- Magnetic field arises due to moving electric charge like in atoms or in conducting materials.

Characteristics of a Magnet

- It has two poles.
- North Pole of magnet coincides with the South Pole of earth's magnet & vice versa.
- Magnetism at poles is greater than at middle.
- Like poles repel while un-like poles attract each other.
- Freely suspended magnet sets itself along N-S direction.

POINT TO PONDER

Poles of magnet can't be separated i.e. If a large magnet is cut into two parts, each part will be a complete magnet in itself having both N and S poles.

- An un-magnetized magnetic material can be magnetized as follows;

(i) By electric method (passing strong D.C)
(ii) By single touch or double touch methods.

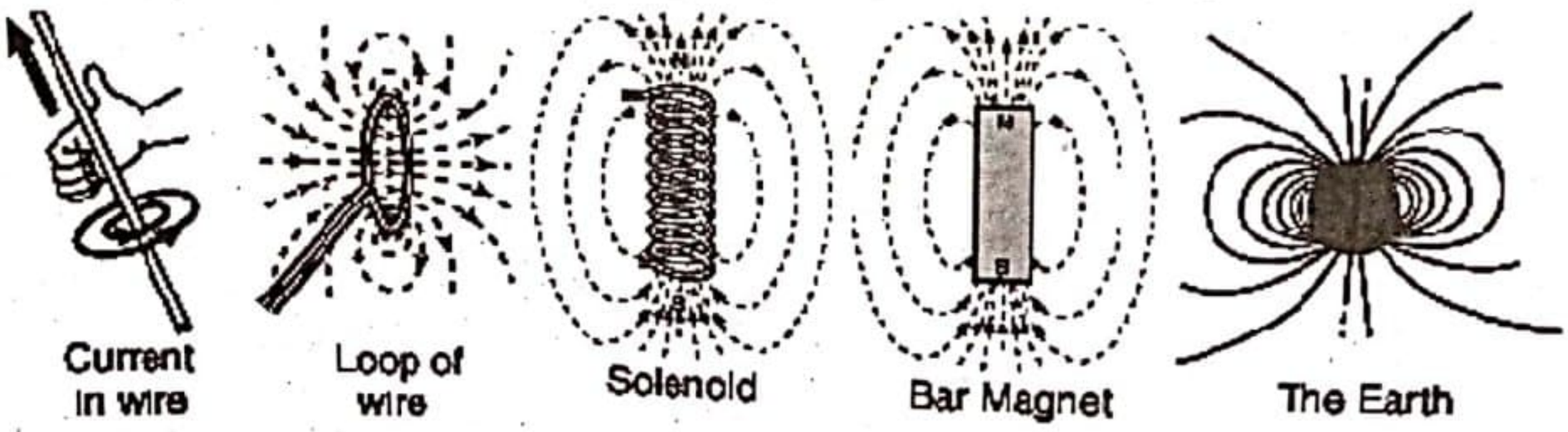
- Magnet can be demagnetized as follows;

(i) By passing A.C
(ii) By heating strongly
(iii) By striking a magnet again and again with a surface like that of earth. e.g by hammering with hammer.

MAGNETIC FIELD

Magnetic field is a region around a magnet within which it can exert its influence upon a magnetic material.

- Magnetic field consists of lines of magnetic force having following properties:



Magnetic Field Sources

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(i) Two magnetic lines of force can't intersect each other.
(ii) Magnetic lines of force fill whole space around a magnet.
(iii) Magnetic lines of force emerge from N-pole and end on S-pole.
(iv) The no. of magnetic lines at a point gives strength of magnetic field.
(v) Longitudinally they tend to shorten their length. It explains attraction between opposite poles.
(vi) Transversely they repel each other. It **explains the repulsion between** two like poles.

- Direction of magnetic field of the current is found by right hand rule for **positive charges** or conventional current.

MAGNETIC FIELD DUE TO CURRENT IN A LONG STRAIGHT WIRE

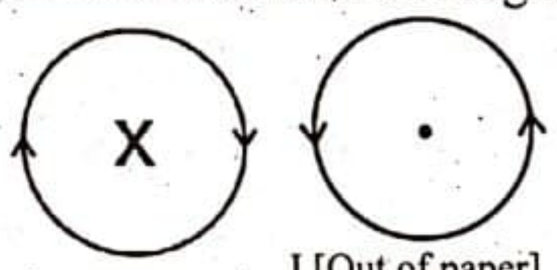
Hans Oersted found that a magnetic field is set up in the region surrounding a current carrying wire.

- The lines of force are circular and their direction depends upon the direction of current.
- The magnetic field lasts only as long as the current is flowing through the wire.

Right Hand Rule

If the wire is grasped in fist of right hand with the thumb pointing in the direction of the conventional current, the fingers of the hand will circle the wire in the direction of the magnetic field

- Following figures should be kept in mind about direction of magnetic field.



I-[Into paper]
B-Clockwise

I [Out of paper]
B-Anti-Clock wise

MAGNETIC FIELD AND MAGNETIC FORCE

Origin of magnetism is motion of charges, was found by **Oersted.**

Force on a Moving Charge in a Magnetic Field

- In an experiment with bar magnet and field produced by charges flowing in a wire (current), following results are drawn;
- If $v \parallel B$, then $F_m = o$
- If $v \perp B$, then $F_m = max.$
- $F_m \perp v$ and $F_m \perp B$
- $F_m \propto q$
- $F_m \propto v$
- $F_m \propto B$
- Single equation containing all above said properties is;

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

- Magnetic field can be given as;

$$B = \frac{F_m}{qv\sin\theta}$$

So magnetic field strength is defined as "magnetic force acting on a unit charge, entering perpendicularly through a magnetic field with speed of 1 m/s".

- If $F_m = 1N$, $q = 1C$, $V = 1m/s$, then $B = 1$ tesla.

$1T = \text{tesla} = \frac{Ns}{Cm}$ = impulse per coulomb per metre. If $\theta=90°$

So, magnetic field is said to be IT, if 1N force acts on a charged particle carrying 1C charge and entering a magnetic field at a speed of 1m/s perpendicularly.

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FORCE ON A CURRENT CARRYING CONDUCTOR IN A UNIFORM MAGNETIC FIELD

- Current carrying conductor experiences a force when placed in a **uniform magnetic field** that is given by; $\overline{F_m}=I(\overline{L}\times\overline{B})$

Where L is length of conductor inside the magnetic field and defined along the direction of conventional current.

- Drift speed of an electron in a conductor is given as;

$$v_d=\frac{I}{nAe}$$

- Magnetic field can be given as; $B=\frac{F_m}{IL\sin\theta}$

So, magnetic field is defined as magnetic force acting on a conductor of 1m carrying 1A current and placed $\perp$ to magnetic field.

- If F_m = 1N, I = 1A, L=1m & $\theta = 90°$, then B= 1 tesla

$$1T=\frac{N}{A\ m}$$

- gauss is a small unit of B. $1T = 10^{-4}$ G

CURRENT CARRYING COIL PLACED IN A UNIFORM MAGNETIC FIELD

Current carrying coil placed in a uniform magnetic field experiences a torque given by;

τ = NIAB cos $\propto$ or NIAB sinθ

Where N = No. of turns in coil

A = Face area of coil,

$\propto$ = Angle between plane of coil and B

θ = Angle between outward normal to the plane of coil and magnetic field

Note: Net force on coil is zero but net torque is not zero.

MAGNETIC FLUX AND MAGNETIC FLUX DENSITY

Magnetic flux is defined as a dot product of magnetic field and area vector of flat surface

$\phi_m = \overline{A}.\overline{B}=AB\cos\theta$ Or $B=\frac{\phi_m}{A\cos\theta}$

Where B is magnetic flux density or flux per unit area normal to the magnetic field lines

- Unit of magnetic flux is weber (Wb).

ϕ_m = 1Wb

if B = 1T

amd A = $1m^2$

and $\theta = 0°$

1Wb = (1T) (1 m^2)

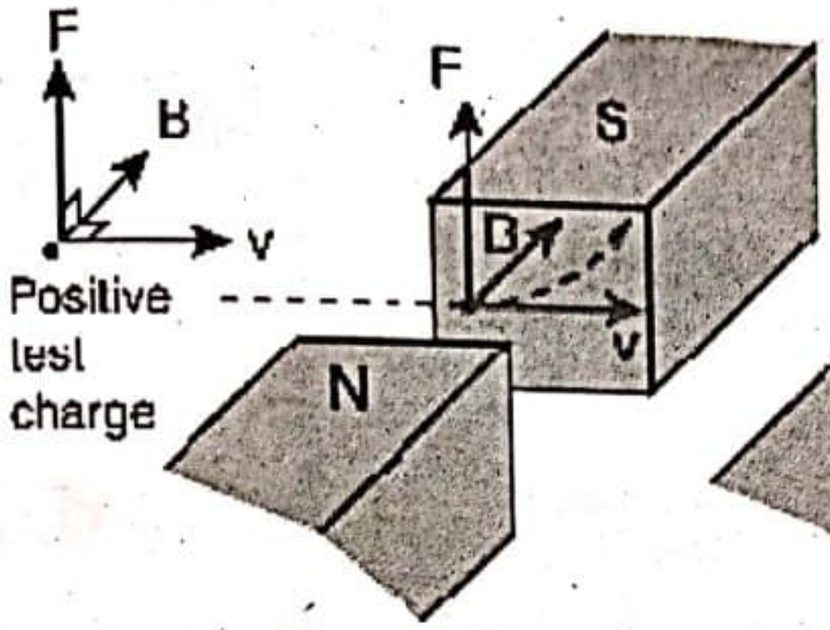
1Wb = 1 N m A^{-1} $\because$ $T = N A^{-1} m^{-1}$

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POINT TO PONDER

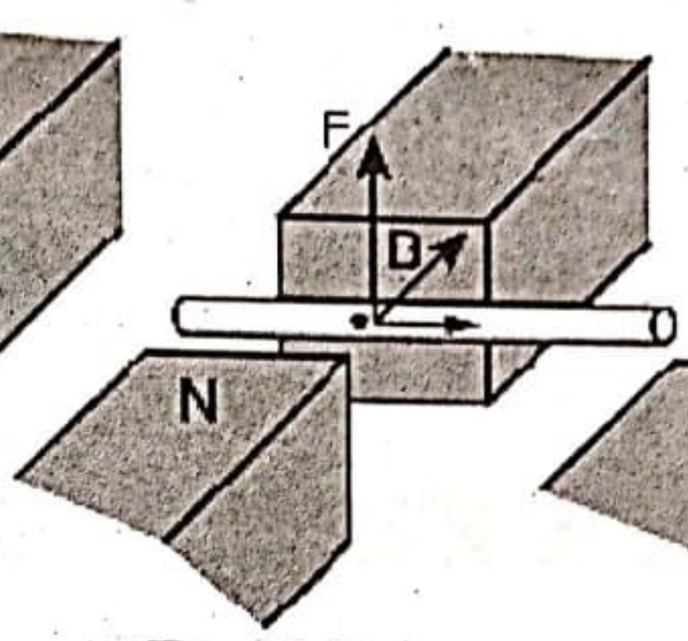
$F = qvB$

F, B, and v are three mutually perpendicular vectors.



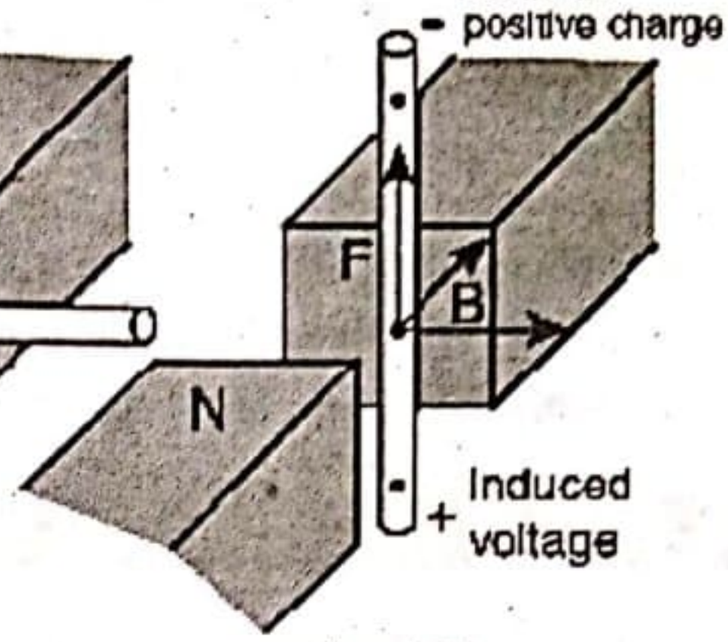
$F = qvB$

Positive charge moving through magnetic field



$F = ILB$

Positive charge moving through stationary wire in magnetic field.



$emf = vBL$

Wire moved through magnetic field by external force.

- Ampere's law is used to find the magnetic field strength

AMPERE'S CIRCUITAL LAW

Definition: The sum of the quantities $\vec{B}.\Delta\vec{L}$ for all path elements into which the complete loop has been divided equals μ_o time the current enclosed by the loop. $\sum_{n=r}^{n}\left(\vec{B}.\Delta\vec{l}\right)_r = u_o I$

I = current enclosed by closed path, where $\mu_o = 4\pi \times 10^{-7}$ **Wb/A m**

Applications: Field due to solenoid $\mathbf{B=\mu_o n\, I}$

Where n = No. of turns per unit length = $\frac{N}{L}$

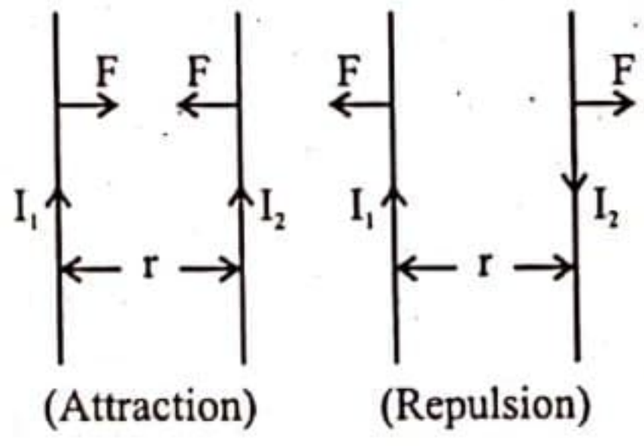
Field due to toroid: $\mathbf{B = \mu_o n\, I}$ where $\mathbf{n = \frac{N}{2\pi r}}$

$\mu_o = 4\pi \times 10^{-7} \frac{Wb}{A\,m}$

Magnetic force between two infinitely long parallel current carrying wires: Let us consider two infinitely long parallel straight current carrying conductors placed at distance from each other. Let I_1 and I_2 be the currents flowing in them.

Then the force acting per unit length of any wire.

$$F = \frac{\mu_o}{4\pi}\frac{2I_1I_2}{r} = 2\times10^{-7}\frac{I_1I_2}{r} \text{ newton/meter}$$



For l meter length of any wire the force

$$F = \frac{\mu_o}{4\pi}\times\frac{2I_1I_2}{r}\times l = 2\times10^{-7}\frac{I_1I_2}{r}\times l \text{ newton}$$

If the currents are flowing in the same direction, force of attraction exists between the wires and if the currents flow in the opposite direction, force of repulsion exists between the wires Where

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Field due to toroid

$$B = \mu_o n I$$

Where $n = N/2\pi r$

SOLENOID AND TOROID

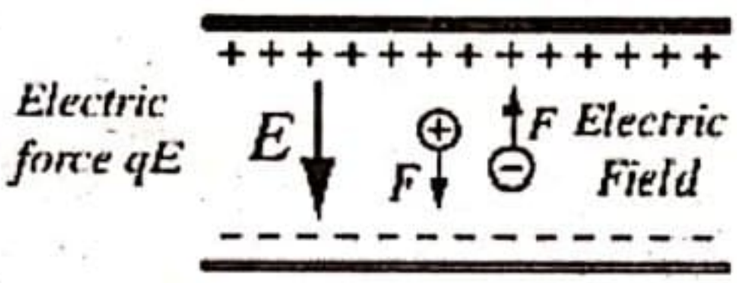
- Solenoid is a cylindrical coil wound on a magnetic or non-magnetic material called core.
- When current flows through a solenoid, the magnetic field is produced inside as well as outside it.
- Field of solenoid is parallel to its length.
- Iron cored solenoid behaves as a bar magnet.
- Toroid is a solenoid **bent into the form of** a circle.
- Field of **toroid is in the form of circular lines** of force.

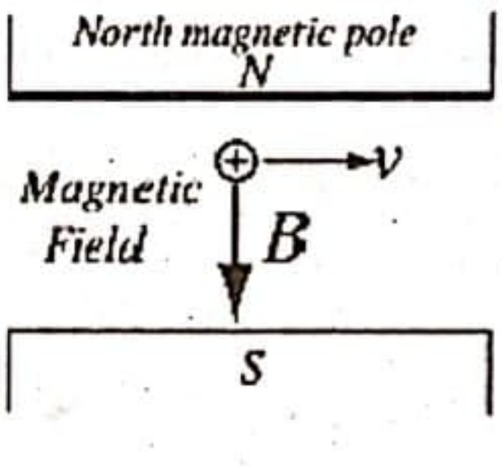
POINT TO PONDER

Is it possible that we keep on increasing the number of turns of coil but the magnetic field strength remains constant? Yes. Why?

FORCE ON CHARGE PARTICLE IN AN ELECTRIC AND MAGNETIC FIELD

As, $\vec{F_e} = q\vec{E}$, and $\vec{F_m} = q(\vec{v} \times \vec{B})$ or $\vec{F} = \vec{F_e} + \vec{F_m}$ or $\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$





Magnetic force of magnitude qvBsinθ perpendicular to both v and B, away from viewer.

Where $\bar{F}$ is called **Lorentz force.**

- Electric force does work
- Magnetic force does no work.

MOTION OF A MOVING CHARGED PARTICLE IN A MAGNETIC FIELD

- When a narrow beam of electron moving with a constant speed V be projected at right angles to a known uniform magnetic field **B** directed into plane of paper, the electrons experience force at right angle to their direction and they will start moving in a circular path as sown in figure.

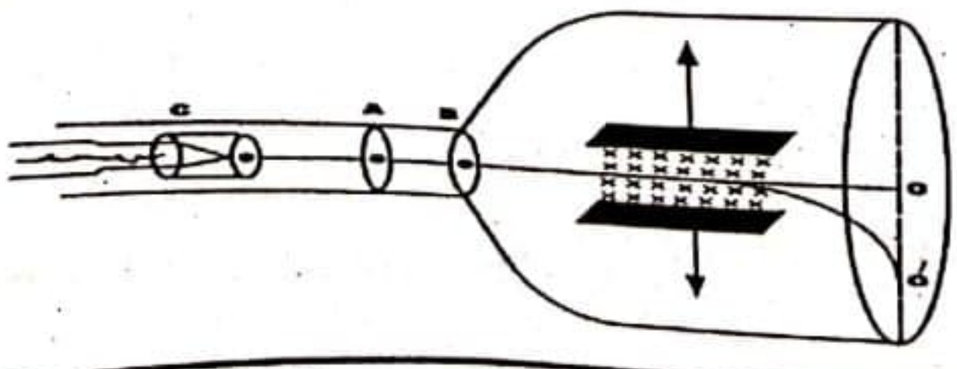
$$F_C = F_m$$

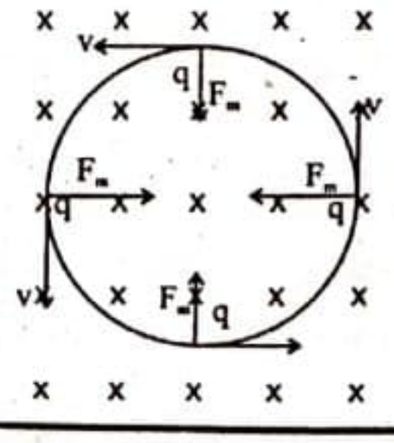
$$\frac{mv^2}{r} = qvB$$

$$mv = qBr$$

$$r = \frac{mv}{qB} = \frac{p}{qB}$$

p is the momentum of particle





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- Magnetic force can do no work on charged particle entering magnetic field because $F_m \perp V$ **(always).**
- Time period of charged particle subjected to circular motion in a magnetic field is given as;

  T = circumference /velocity

  $= 2\pi R/v \qquad = 2\pi\, mv/qBv$

  $= 2\pi m/qB$
- Frequency of charged particle circulating in a magnetic field is given as;

  $f = 1/T$

  $f = qB/2\pi m$

  It is known as **cyclotron frequency.**
- If a particle has both components of velocity $V_\perp$ and $V_\parallel$ and is allowed to enter a magnetic field B, it **adopts helical motion.**



- Force at 90° to the velocity, changes **direction and not the speed of the particle.**

e/m RATIO

- e/m of a charged particle can be given as; $\frac{e}{m} = \frac{v}{Br}$

Where R is determined by **Thomson's apparatus** while velocity is determined by following two methods:

POINT TO PONDER

The e/m of a proton is greater or less than an electron?

Potential difference method:

$$v = \sqrt{2V_o \frac{e}{m}}$$

So that

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

Velocity selector method:

$$v = \frac{E}{B}$$

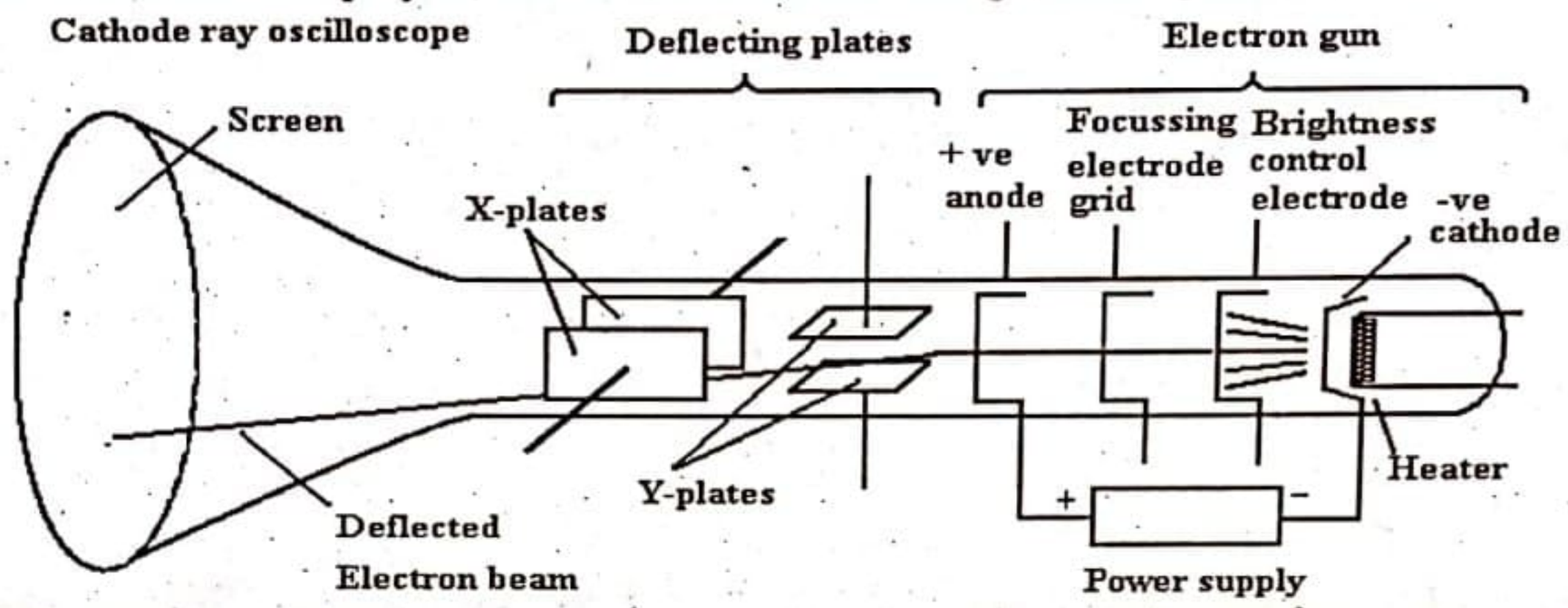
so that $$\frac{e}{m} = \frac{E}{B^2 r}$$

The value of $\frac{e}{m}$ is equal to 1.7588×10^{11} C/kg

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CATHODE RAY OSCILLOSCOPE (CRO)

- It is a high-speed graph-plotting device same as **picture tube of T.V** set or monitor of a computer.
- Electron beam is produced and deflected by voltage.
- Fluorescent screen make it visible.
- A grid is used to control the number of electrons.
- The grid is at a negative potential with respect to cathode.
- Electrons are accelerated by anode.
- CRO is used for displaying the waveform of given **voltage.**
- Once the waveform is displayed, we can measure the voltage, its frequency and phase.



TORQUE ON CURRENT CARRYING COIL

- A current carrying coil placed in magnetic field, will be rotated, in magnetic field, producing torque.

$$\tau = BINA \cos \alpha$$

Where α is the angle made by the **plane** with the **magnetic field.**

N is the **number of turns** of the coil

A is the **area of** the **coil.**

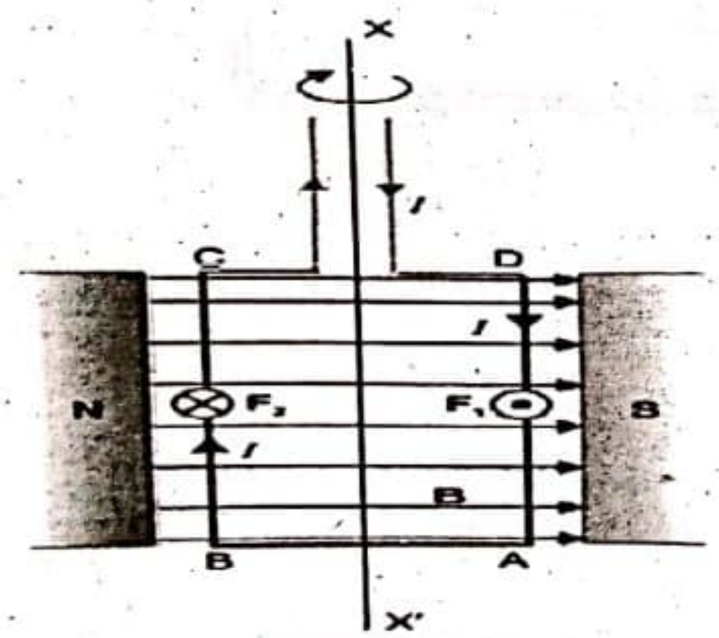
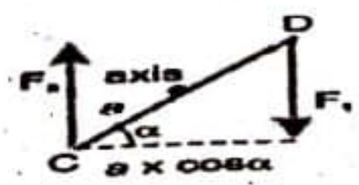
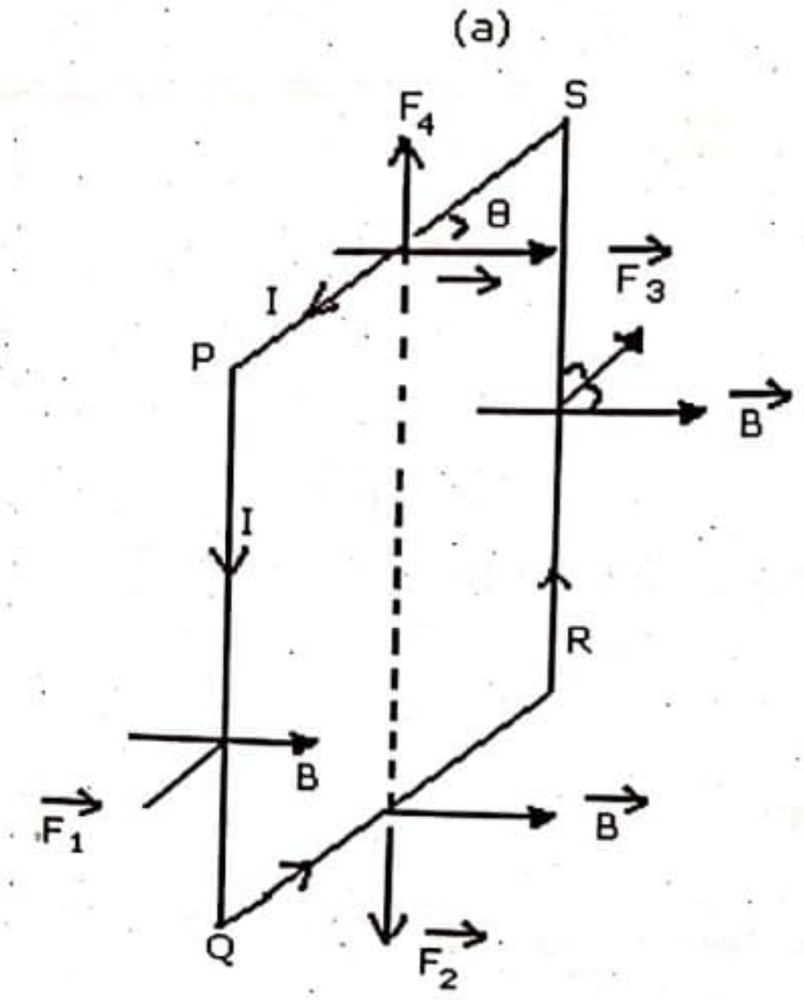


Fig 14.15 (a)



(Top view of coil)

Fig 14.15 (b)



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ELECTRICAL MEASURING INSTRUMENTS

Electrical measuring instruments are those devices, which convert **electrical energy into mechanical energy.**

Examples

[i] Galvanometer [ii] Voltmeter [iii] Ammeter [iv] AVO meter

POINT TO PONDER

All the electrical measuring instruments can only read current because current is the characteristic that can be measured as it can show physical effects. So all measuring instruments show different scales only but they are measuring current e.g. a voltmeter can measure voltage but actually it measures current and display it on the scale of volts.

GALVANOMETER (G.M)

Galvanometer is used for the detection of both A.C and D.C currents & voltages.

Principle of G.M

"Current carrying coil experiences electric torque $\tau = NAIB\cos\alpha$, when placed in a magnetic field."

- Galvanometer is a parent instrument, which can be converted into voltmeters and ammeters etc.

Types

(i) Moving coil G.M (MCGM)

(ii) Moving magnetic G.M (MMGM)

Major Parts of Moving Coil G.M

(ii) pole piece made concave

(iii) suspension wire

(iv) lamp-scale arrangement

(v) coil

(vi) hair springs.

- When coil of G.M stops after deflection, then-

Deflecting torque = Restoring torque

$$I\,N\,A\,B\cos\alpha = c\theta$$

Here $\alpha = 0$,

$$I = \frac{c\theta}{BAN} = K\theta$$

Where c represents couple per unit twist or torsion constant that depends upon the nature and **geometry of suspension wire.**

- Galvanometer constant is given as;

$$K = C/BAN$$

- A G.M can be made sensitive by making $K = C/BAN$ small.

(i) C is made small by increasing the length and decreasing the diameter of suspension wire

(ii) A, B, N are made large

Note: Best suggestion is to make **B as strong as possible**

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POINT TO PONDER

The needle of the galvanometer should stop quickly at the mean position, thus should suffer lesser oscillations. So the galvanometers are designed such that these oscillations can be minimized. So they are critically damped. Such type of galvanometer is called dead head galvanometer.

Modifications in Weston-type Galvanometer

i. Suspension wire is replaced by shaft with pivot.
ii. Lamp-scale arrangement is replaced by light aluminum needle and graduated scale.

AMMETER

Galvanometer is used for the measurement of current when converted into ammeter.

- G.M can be converted into A.M by connecting a shunt (low resistance) in parallel to its coil.

Value of shunt is given as;

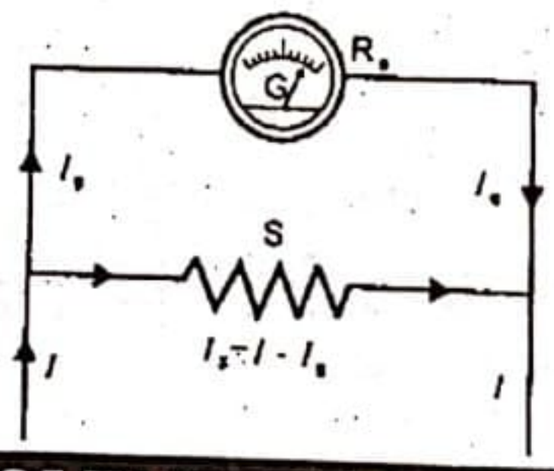
$$R_s = \frac{I_g R_g}{I - I_g}$$

Where I is called range.

- To increase the range of A.M, shunt should be made more small
- Range of A.M is given by;

$$I = I_g \left[\frac{R_g + R_s}{R_s} \right]$$

- A.M is always **connected in series.**
- An ammeter must have a very low resistance so that it does not disturb the circuit resistance.



VOLTMETER

- Voltmeter is a high resistance G.M.
- To convert G.M into V.M, a high resistance R_h is connected in series with its coil.
- High resistance (multiplier), which converts G.M to V.M is given as;

$$R_h = \frac{V}{I_g} - R_g$$

Where V is called **range of voltmeter**

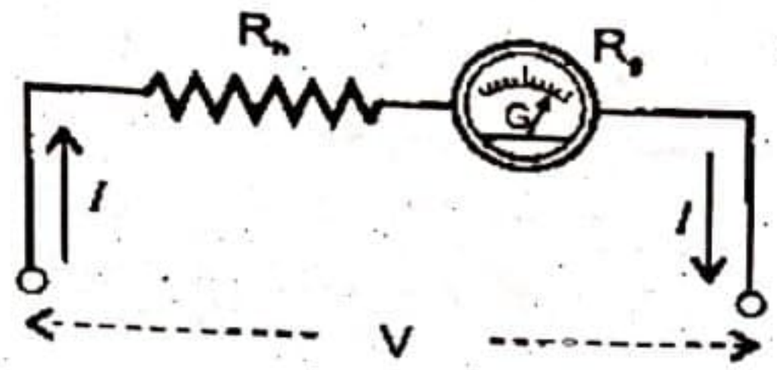
- Range of voltmeter is given as;

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

It shows that $V \propto R_h$ so making resistance R_h higher can make a V.M **more sensitive**

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- Voltmeter is always **connected in parallel.**
- Reading of V.M is not accurate as it draws some current for its working. Hence it measures **less voltage than actual.**
- For accurate measurement of voltage, **potentiometer is used.**



OHM METER

- Rapidly measures resistance.
- Adjustable resistance along with cell is used internally in ohmmeter. This adjustable resistance is called current limiting resistance

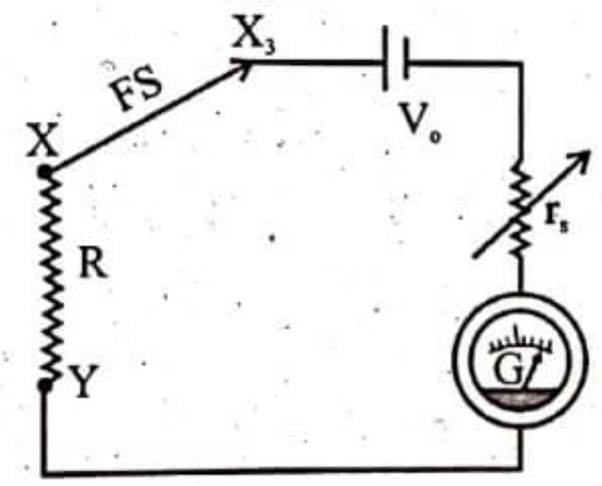
AVO METER

AVO meter is an electrical measuring instrument used for the measurement of current, voltage and resistance

A for Amp , V for Volt , O for Ohm

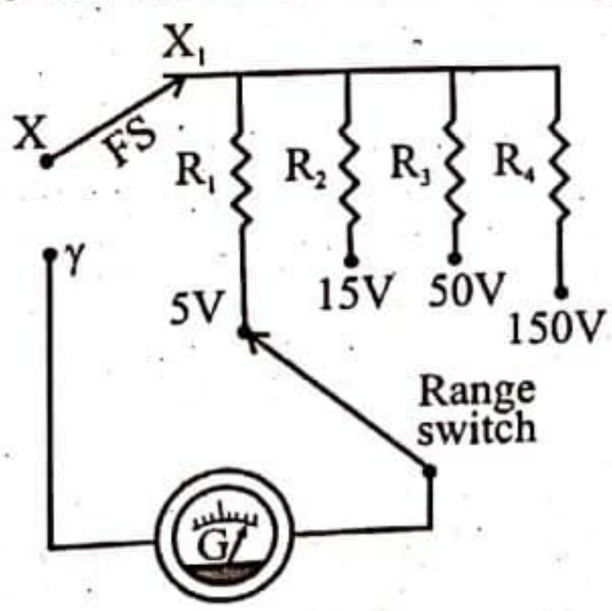
AVO Meter as Ohmmeter

- Circuit of AVO meter measurement of resistance is given below:



AVO Meter as Voltmeter

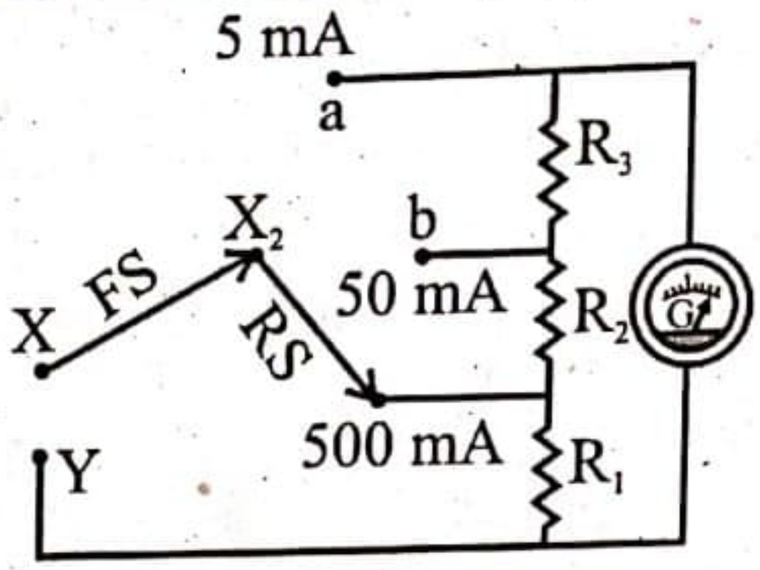
- Circuit of AVO meter for measurement of **voltage is** given below;
- Set of resistance connected in series to coil of **G.M is called multiplier,** as shown below:



AVO Meter as Ammeter

- Set of shunts connected in parallel is called universal shunt or Aryton shunt

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- No. of scales on AVO meter are three.

(i) Ohm scale

(ii) Current scale both for A.C & D.C

(iii) Voltage scale both for A.C & D.C

DIGITAL MULTIMETER (DMM)

It is AVO meter but have digital **displaying.**

- It gives decimal counting, polarity and unit for V, I or R.
- It is free from human errors of **polarity selection.**

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15 CHAPTER

ELECTROMAGNETIC INDUCTION

INTRODUCTION

Orested discovered magnetic field due to current carrying coil.

- **Faraday** discovered electromagnetic induction (production of induced emf and induced current by the time rate of change of magnetic flux $\phi=BA\cos\theta$
- The induced current depends upon the speed with which the conductor moves and upon the resistance of the loop.
- The induced current can be increased by-
  - ✦ Using a stronger magnetic field
  - ✦ Moving the loop faster
  - ✦ Replacing the loop by a coil of many turns

Point to Remember

As magnetic flux is

$\Phi_m=BA\cos\theta$

So the change in flux can be caused as:-

- Change in magnetic field strength.
- Change in projected area.
- Possible change in the orientation of coil in field.

FARADAY'S LAW

First Law

Induced emf lasts till the **flux remains changing.**

Second Law

Induced emf is directly proportional to the time rate of change of magnetic flux i.e.

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

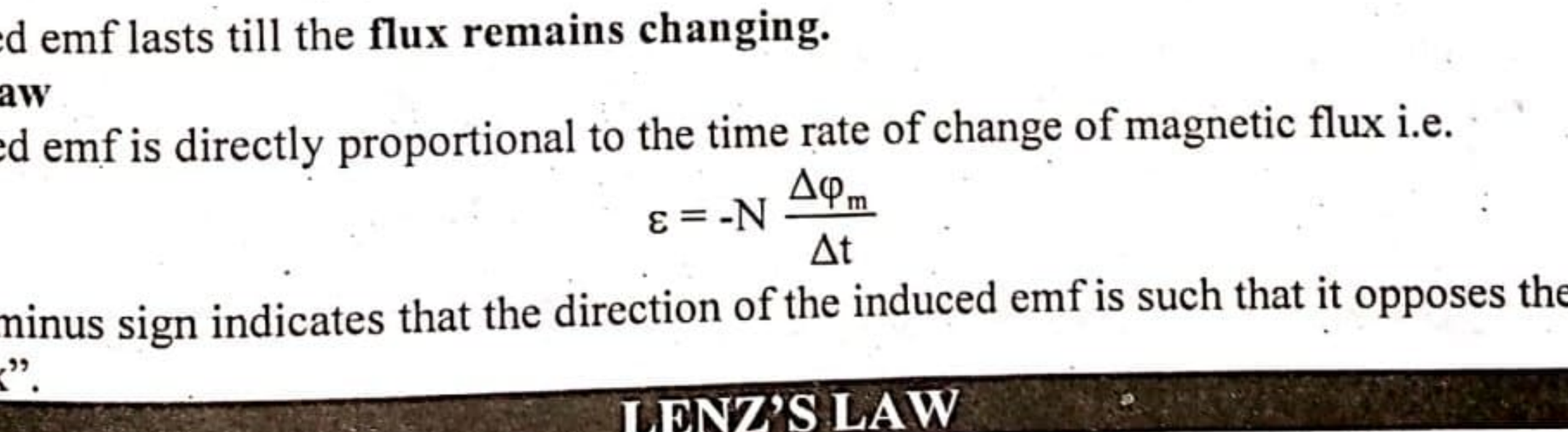
"The minus sign indicates that the direction of the induced emf is such that it opposes the change in flux".

LENZ'S LAW

"The direction of the induced current is always so as to oppose the change which causes the current".

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

- Lenz's law is in accordance with the law of conservation of energy.



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- The mechanism of generation of induced e.m.f is such that energy fed to change flux, changes to magnetic force, which moves free electrons to cause the current and **hence induced e.m.f.**
- Following ways can change magnetic flux (or in other words, can produce induced e.m.f):-
  - ✦ Motion of magnet.
  - ✦ Motion of coil.
  - ✦ Relative motion of coil and magnet.
  - ✦ Change of current.
- If there does not exist Lenz's law then perpetual motion machine of 1st kind was possible. Thus the process will be self-perpetuating.

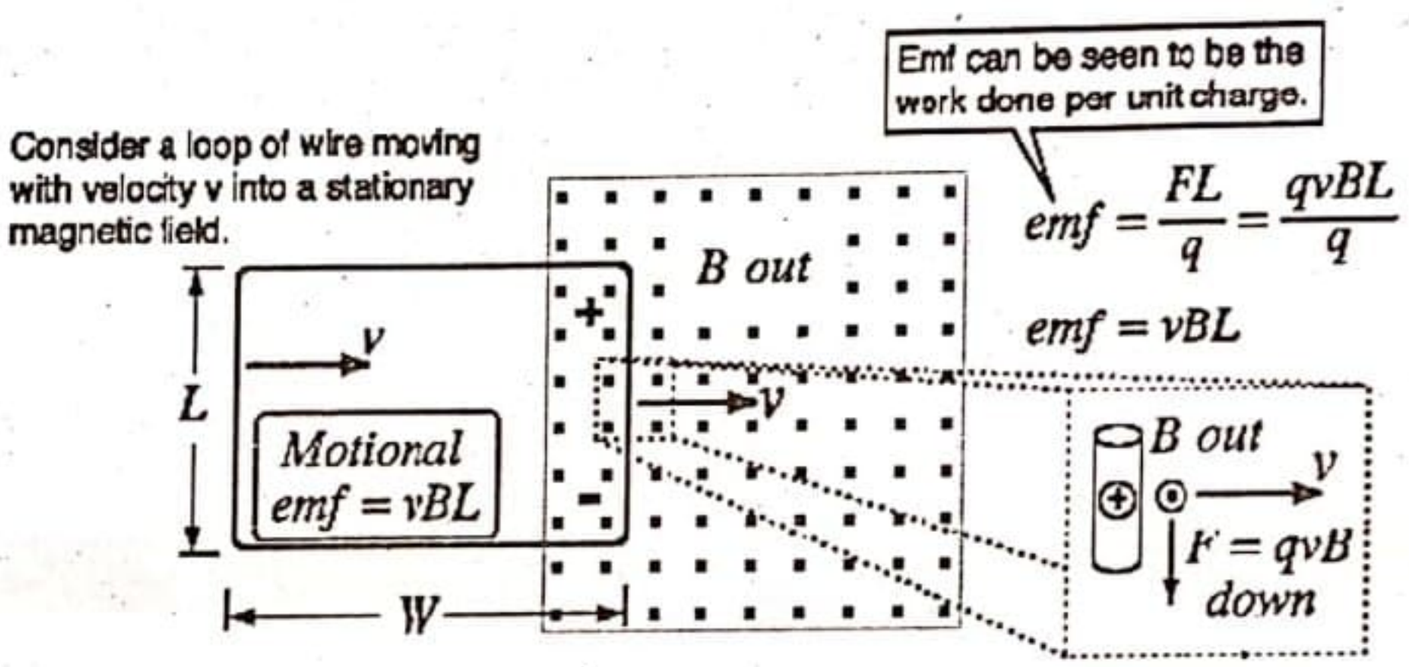
MOTIONAL emf

The emf induced by the motion of a conductor across a magnetic field is called motional emf.

$$\epsilon_{(motional)} = -vBL$$

Where v = speed of the conductor

L = length of the conductor



- If there is some orientation of the coil to the magnetic field, then

$$\varepsilon_{(motional)} = -vBL\sin\theta$$

Where θ is the angle between v & B.

- The unit of motional emf is volt.
- Magnetic field strength is considered to be uniform while deriving the above expression.

MUTUAL INDUCTION & SELF INDUCTION

- Mutual induction is a phenomenon in which a changing current in one **(primary)** coil induces an emf in another coil **(secondary)**

$$e.m.f_{sec} = -M\ \Delta I_P/\Delta t$$

Where $M = N_s\Phi_s/I_p$ called mutual inductance.

- Mutual inductance is defined as the ratio of back e.m.f in the secondary to the rate of change of current in primary coil.

$$M = \frac{-emf}{\Delta I_P/\Delta t}$$

- **Self-induction** is a phenomenon of generation of induced e.m.f in a coil due to change of current in itself.

$$e.m.f_{self} = -L\frac{\Delta I}{\Delta t}$$

Where L is called self inductance. Also $\mathbf{N\Phi = LI}$

- Self-inductance is defined as the ratio of back e.m.f to rate of change of current in the same coil.

$$L = \frac{-emf_{self}}{\Delta I/\Delta t}$$

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- SI unit of mutual and self-inductance is henry (H).

(i) $M = 1\ H$ if $e.m.f_{sec} = 1V$ and $\Delta I_p/\Delta t = 1A/s$

Mutual inductance is said to be 1 H if a current change in primary at a rate of $1A\ s^{-1}$ produces e.m.f of 1 volt in secondary.

(ii) $L = 1\ H$ if $e.m.f = 1V$ and $\Delta I/\Delta t = 1\ A\ s^{-1}$

Self-inductance is said to be 1H, if **current changing at the rate of 1 A/sec produces an e.m.f of 1V in the coil itself.**

ENERGY STORED IN AN INDUCTOR

Inductor is simply an insulated coil that **offers very small resistance** to D.C current but offers **high resistance to A.C current.**

- In case of capacitor, energy is stored in electric field between the plates. Similarly, energy is stored in magnetic **field of the inductor.**
- Work done by the battery to move charges **against the induced emf** is $\mathbf{W = \frac{1}{2} LI^2}$
- This work is stored as potential energy in the inductor as $\mathbf{U_m = \frac{1}{2} LI^2}$

Also $L = \mu_o n^2 A l$

$$U_m = \frac{1}{2}(\mu_o n^2 A l) I^2$$

As $B = \mu_o n I$

Then $$U_m = \frac{1}{2} B^2 \frac{Al}{\mu_o}$$

As $Al = \text{Volume}$

Then energy density is $$U = \frac{U_m}{Al} = \frac{1B^2}{2\mu_o}$$

or $$U = \frac{1}{2}\frac{B^2}{\mu_o} \Rightarrow U \propto B^2$$

- Inductor in an A.C circuit always resists the abrupt change in current.

POINT TO PONDER

The density of energy storage in an inductor is directly proportional to the square of the magnetic field strength provided all other factors remains constant.

SERIES AND PARALLEL COMBINATION OF INDUCTANCES

Coils in Series: If two coils of inductance L_1 and L_2 are connected in series then

$$\varepsilon = \varepsilon_1 + \varepsilon_2 \quad \text{or} \quad L_s \frac{\Delta I}{\Delta t} = L_1 \frac{\Delta I_1}{\Delta t} + L_2 \frac{\Delta I_2}{\Delta t} \quad \left[\text{as } \varepsilon = -\frac{L\Delta I}{\Delta t}\right]$$

However in series as current remains same $I = I_1 = I_2$ or $$\frac{\Delta I}{\Delta t} = \frac{\Delta I_1}{\Delta t} = \frac{\Delta I_2}{\Delta t}$$

Therefore $\mathbf{L_s = L_1 + L_2}$

Coils in Parallel: As in case of parallel combination of coils, the current divides, i.e.

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$$I = I_1 + I_2 \quad \text{or} \quad \frac{\Delta I}{\Delta t} = \frac{\Delta I_1}{\Delta t} + \frac{\Delta I_2}{\Delta t}$$

$$\frac{\varepsilon}{L_p} = \frac{\varepsilon_1}{L_1} + \frac{\varepsilon_2}{L_2} \quad \left[\text{as} \quad \varepsilon = -L\frac{\Delta I}{\Delta t} \text{ i.e., } \frac{\Delta I}{\Delta t} = -\frac{\varepsilon}{L}\right]$$

However, in parallel, as potential same, i.e., $\varepsilon = \varepsilon_1 = \varepsilon_2$

Therefore $\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2}$ i.e., $L_p = \frac{L_1 L_2}{L_1 + L_2}$

A.C & D.C GENERATOR

Current generator is a device, which converts mechanical energy into **electrical energy in the presence of magnetic field.**

- The principle of generator is that emf is induced across a coil rotating in a magnetic field due to change of **magnetic flux.**
- Main parts of A.C generator
  - ✦ Pole pieces (U-shape magnet) with concave poles.
  - ✦ Armature (assembly of coil on iron cylinder)
  - ✦ Slip rings (as connector)
  - ✦ Carbon brush (external supply)
- emf is induced by the side of loop intersecting the **magnetic** field.
- Total emf for N number of loops is given as;

$\varepsilon = N(2vB\ell \sin\theta)$ also $\varepsilon = N\omega AB \sin \omega t$

$\varepsilon_{max} = N\omega AB$ when $\theta = 90°$

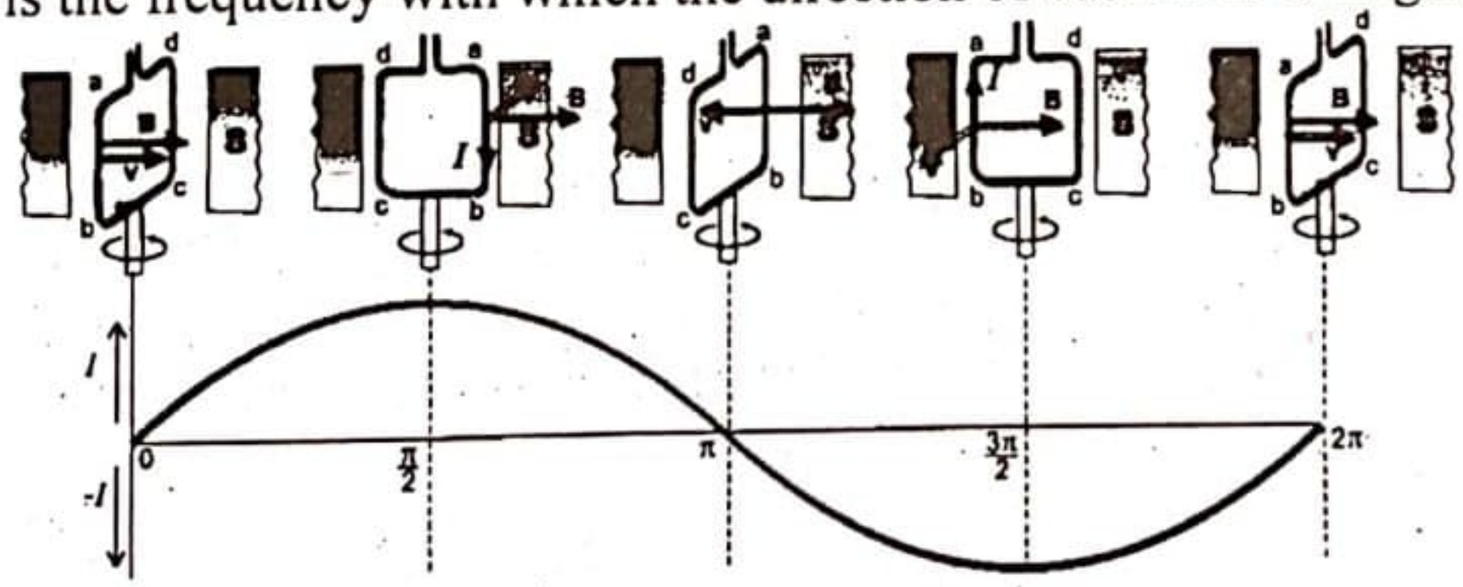
then $\varepsilon = \varepsilon_{max} \sin \omega t$ If $\omega = 2\pi f$, then

$\varepsilon = \varepsilon_{max} \sin 2\pi ft$

In terms of potential difference, $\mathbf{V = V_o \sin 2\pi ft}$

In terms of current, $\mathbf{I = I_o \sin 2\pi ft.}$

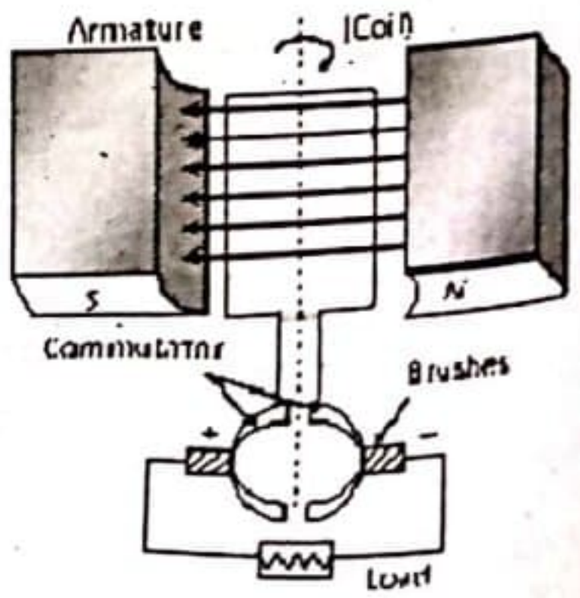
where f is the frequency with which the direction of current is changing.



- In Pakistan f = 50Hz, it means 50 times in a second direction is changing.

If the current produced by the generator is direct current, then the generator is called dc generator.

dc generator consists of (i) Armature (coil) (ii) Magnet (iii) Commutator (iv) Brushes



In dc generator commutator is used in place of slip rings. The commutator rotates along with the coil so that in every cycle when direction of 'e' reverses, the commutator also reverses or makes contact with the other brush so that in the external load the current remains in the some direction giving dc.

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- D.C generator produce uni directional pulsating D.C, not pure D.C
- For pure D.C many coils are wound around cylindrical core

Back Motor Effect in Generator

- The device in electric circuit that consumes electric energy (electricity) is known as **load.**
- The greater the load, the larger the current is supplied by the generator (indicated by sound of generator)
- "When the circuit is closed, a current is drawn through the coil. The magnetic field exerts force on the current carrying coil. This force produces a counter torque that opposes the rotational motion of the coil. This effect is called **back motor effect of generators.**"
- According to energy conservation law, the energy consumed by the load must come from the energy source used to **drive turbines.**
- The larger the current drawn by the load, the greater is the **counter torque produced.**

D.C MOTORS

A motor is a device which converts **electrical energy** into **mechanical energy.**

- A generator running backward is called motor.
- Principle of motor is that whenever a current carrying coil is placed in a magnetic field it experiences a couple of forces, which causes torque.

Back e.m.f Effect in Motors

- The self induced emf (ε) in a motor opposes the voltage v **running the motor**. This induced emf is called the **back emf of motor.**
- The magnitude of the back emf increases with the speed of motor.
- V & Є are in opposite polarity.
  i.e. current flowing in motor is

$$I = \frac{(V - \varepsilon)}{R} \quad \text{or} \quad V = \varepsilon + IR$$

- As the motor speeds up, the back emf increases and the **current** becomes smaller and smaller. So current should be kept sufficient to provide torque.
- If motor is overloaded, the back emf decreases and allow the motor to draw more current
- If motor is overloaded beyond its limits, the current could be so high that it may **burn** the motor coil.

POINT TO PONDER

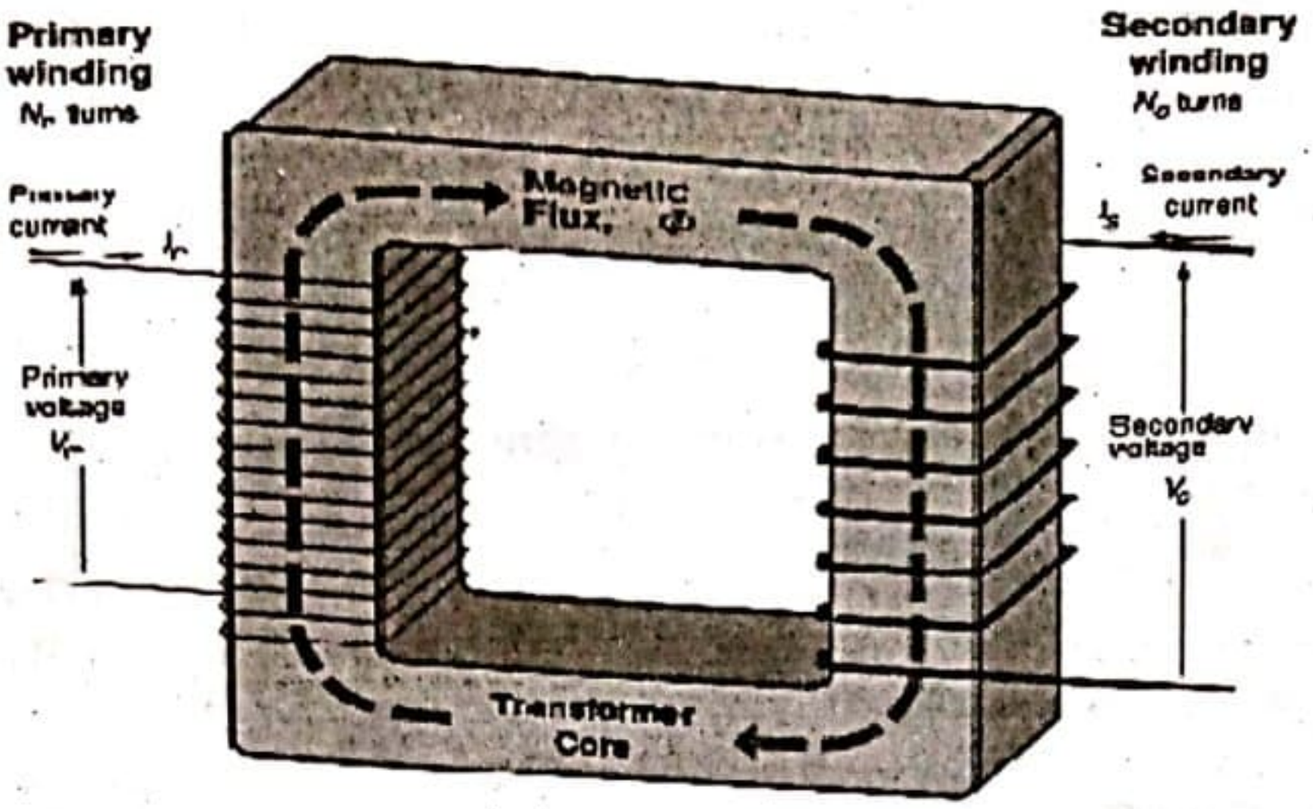
Transformer is one of the static devices in the electrical appliances. So there is no loss of energy in friction. Hence they can have higher efficiencies. We can achieve up to 95% efficient transformer

TRANSFORMER

Transformer is an electromagnetic device used to step up or step down A.C voltage or A.C current, not D.C.

- Principle of transformer is **the mutual induction.**
- Coil of transformer where input is applied is called **primary** coil while other where out put is obtained is called **secondary coil.**
- Core consist of laminated punched sheets of soft iron on which coil is wound.
- Lamination of core is done to reduce **eddy current losses** (eddy current is an induced current produced in a core).

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Information

- **step down**
  - Np > Ns,
  - Current ratio with voltage Vp/Vs = Is/Ip
- **Transformer losses**
  - Core losses (Hysterises loss)
  - Copper losses
  - Eddy current losses
- **step up**
  - Turn ratio with current
  - Np/Ns = Vp/Vs

- Transformer can't step up or step down the **energy or power.**
- Transformer consumes very litter part of input power so it can be kept running for hours without considerable loss of power.

$$\frac{V_s}{V_P} = \frac{N_s}{N_P} = \frac{I_P}{I_s}$$

Losses in Actual Transformer: The losses in transformer occur in core and winding.

Types of Losses in Transformer

- **Copper Losses in Winding:** Due to resistance of the windings of primary and secondary coils, some electrical energy is always lost in the form of heat energy.

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- **Flux Losses:** The coupling of the primary and secondary coils is never perfect and whole of the magnetic flux produced in the primary coil does not link the secondary coil. This results in some energy loss.
- **Iron Losses in Core:** Iron losses are of two types: Eddy current loss and hysterisis loss

(i) **Eddy Current Loss:** Due to the periodically varying nature of A.C. supplied in primary, the flux associated with core changes and, therefore, eddy currents are induced in it.

Eddy currents induced in the core are undesirable as they heat the core and result in energy loss. To minimize the eddy current losses, core is laminated.

(ii) **Hysterisis loss:** The alternating current flowing through the coils magnetizes and demagnetizes the iron core again and again. Therefore, during each cycle of magnetization, some energy is lost due to hysterisis. To minimize this loss we choose material of core of smaller hysterisis loss generally soft iron.

Efficiency of Transformer:

Ideal transformer, efficiency is 100 % or 1 but in actual transformer output power is always less than input power, so efficiency also always less than 100%. In general efficiency of transformer is very high and is of the order of 90%.

Efficiency is given by $\eta = \frac{\text{Output power}}{\text{Input power}} \times 100$. In terms of secondary and primary voltages and currents, $\eta = \frac{V_s I_s}{V_p I_p}$. Also since, **Input = Output + Losses, so** $\eta = \frac{\text{Output power}}{\text{output power + Losses}}$

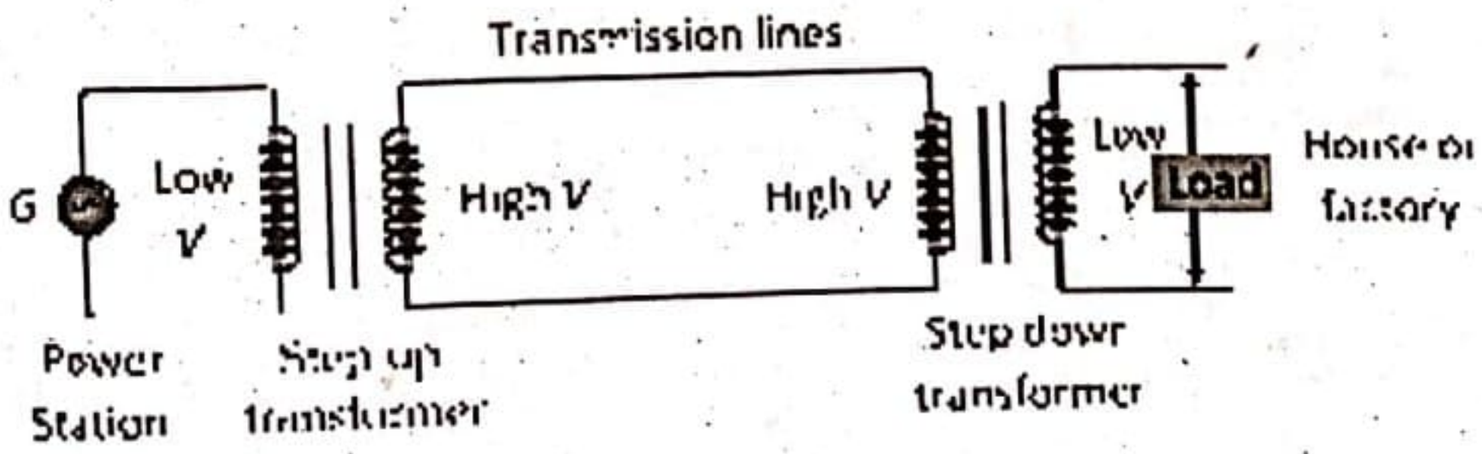
Uses of Transformer: A transformer is used in almost all ac operations e.g.

(i) In voltage regulators for TV, refrigerator, computer, air conditioner etc.

(ii) In the induction furnaces

(iii) Step down transformer is used for welding purposes.

(iv) In the transmission of ac over long distance.



(v) Step down and step up transformers are used in electrical power distribution.

(vi) Audio frequency transformers are used in radiography, television, radio, telephone etc.

(vii) Radio frequency transformers are used in radio communication.

(viii) Transformers are also used in impedance matching.

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16 CHAPTER ALTERNATING CURRENT

INTRODUCTION

A.C is the current produced by a voltage source **that reverses its polarity with time.**

- Time period T of alternating current or voltage (that produced it) is the time interval T in which the source voltage **reverses its polarity once.**
- The sinusoidal waveform of A.C is a graph between **voltage and time.**
- **The voltage of A.C generator varies with time and at an instant.**

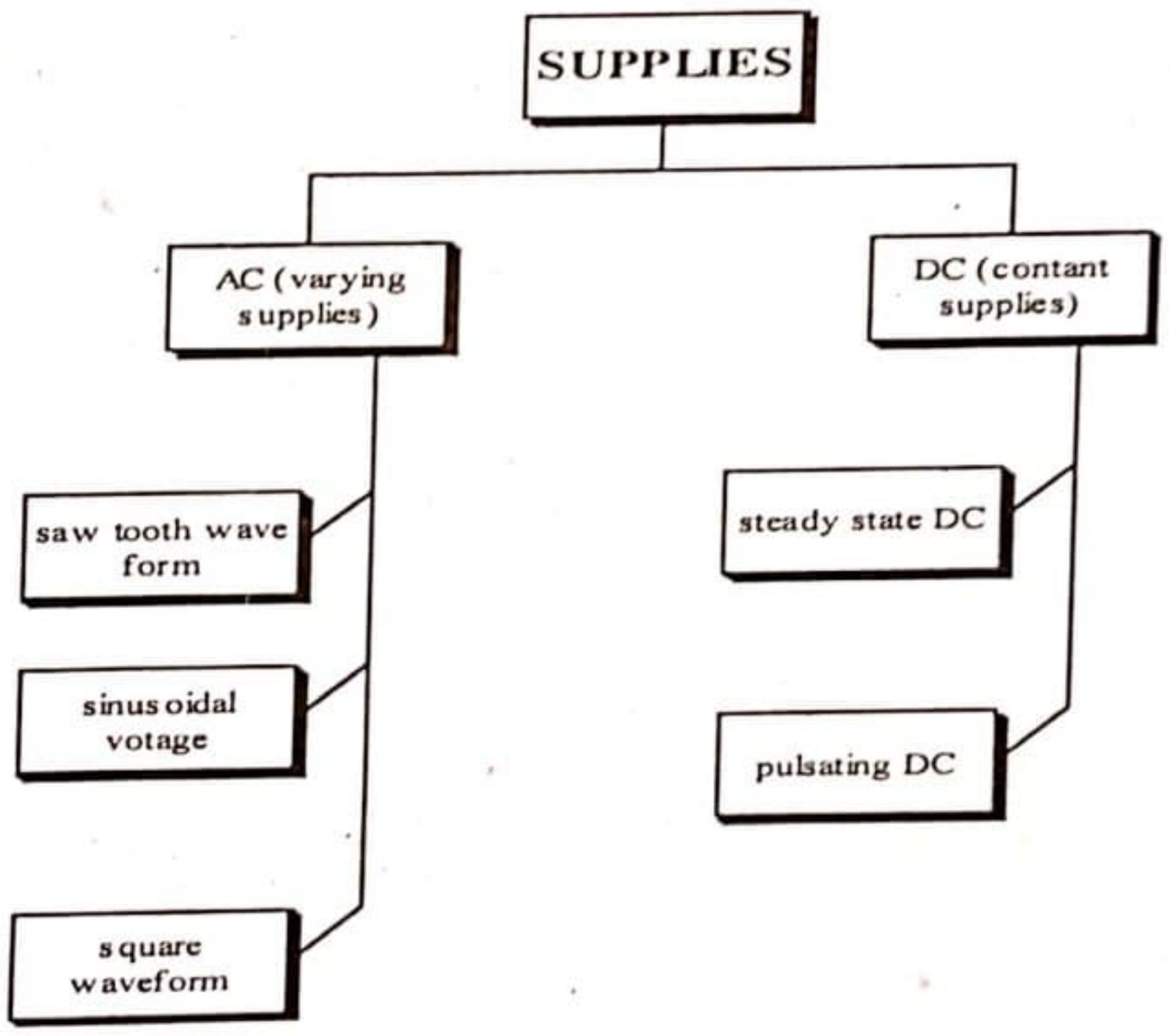
$$V = V_o \sin \omega t$$

$$= V_o \sin \frac{2\pi}{T} t$$

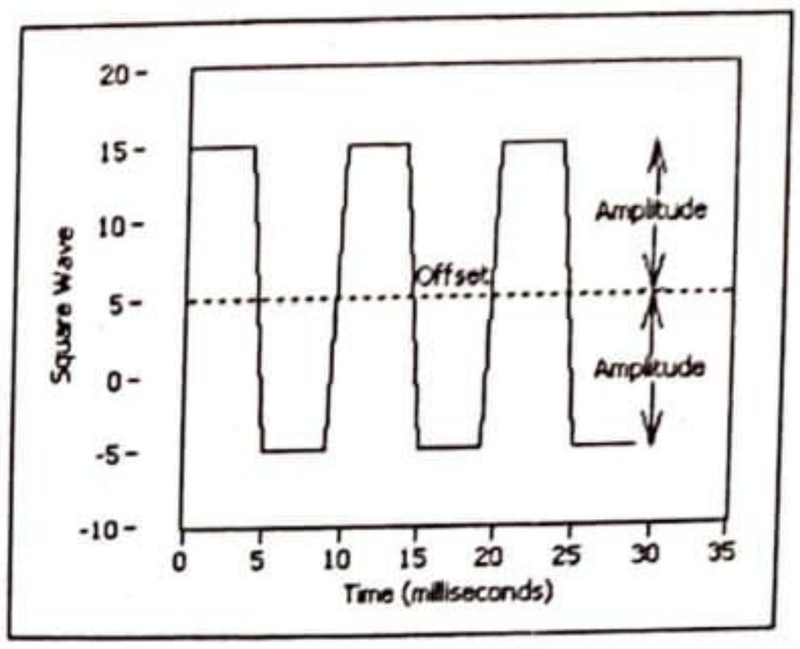
$$= V_o \sin 2\pi f t$$

$$\mathbf{V = V_o \sin 0}$$

Where $\theta = \omega t$ is the angle through which coil rotates in time 't'. θ is the phase which specifies instantaneous value.

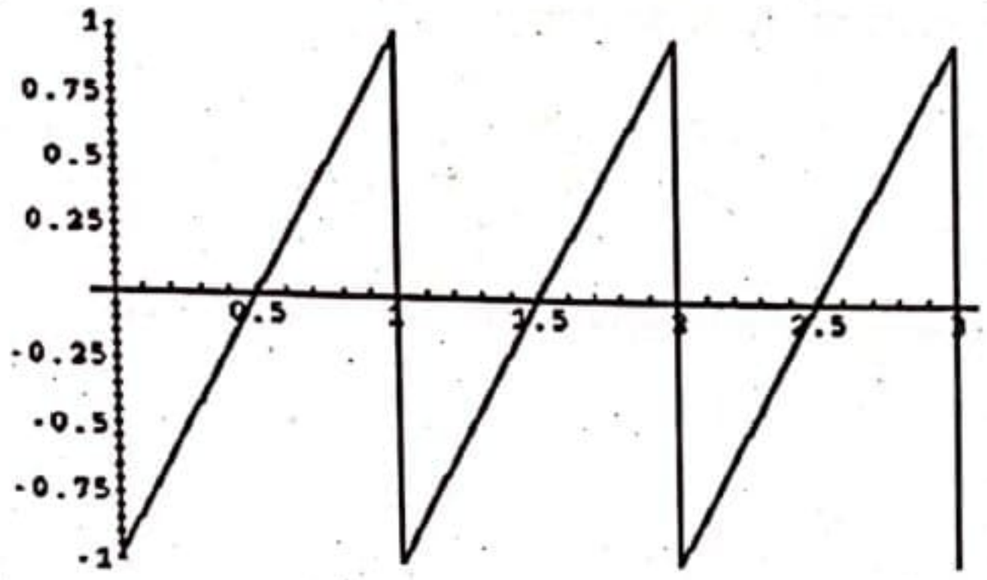


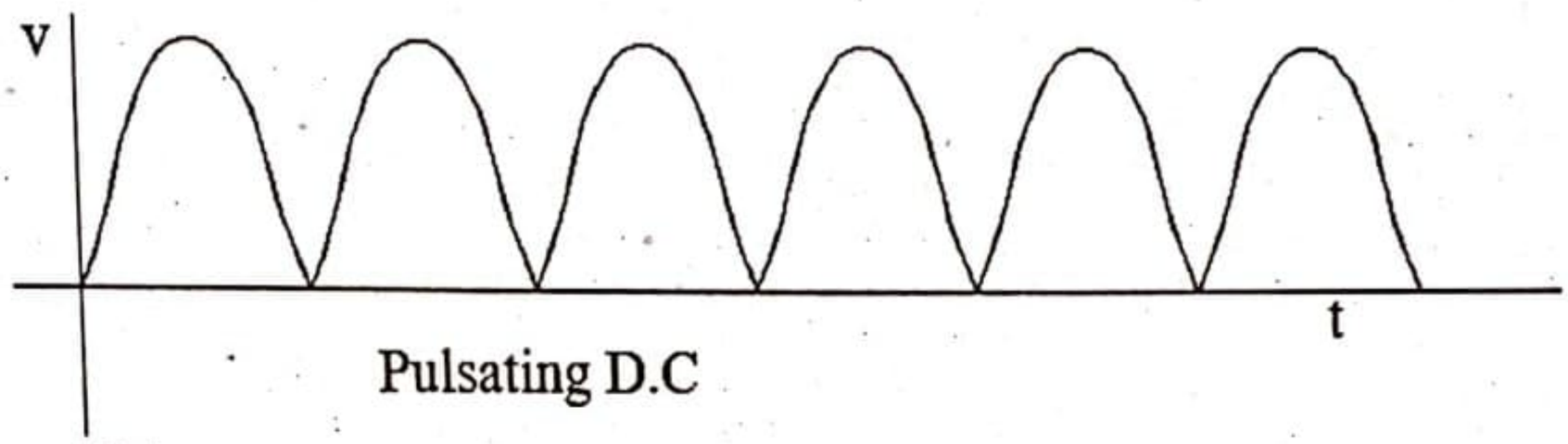
Square Wave



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Sawtooth Wave





Pulsating D.C

Instantaneous Values

The value of voltage or current that exists at any given instant 't' in a circuit is known as instantaneous value.

$$V_{inst} = V = V_o \sin\theta = V_o \sin 2\pi ft = V_o \sin \omega t$$

or $$I_{inst} = I = I_o \sin\theta = I_o \sin 2\pi ft = I_o \sin \omega t$$

V is the instantaneous value between $+V_o$ & $-V_o$

- Sinusoidal graph is the set of all instantaneous values.

Peak Value (V_o or I_o)

It is the highest value for **voltage or current**

Peak to Peak Value

It is the sum of +ve & -ve peak values

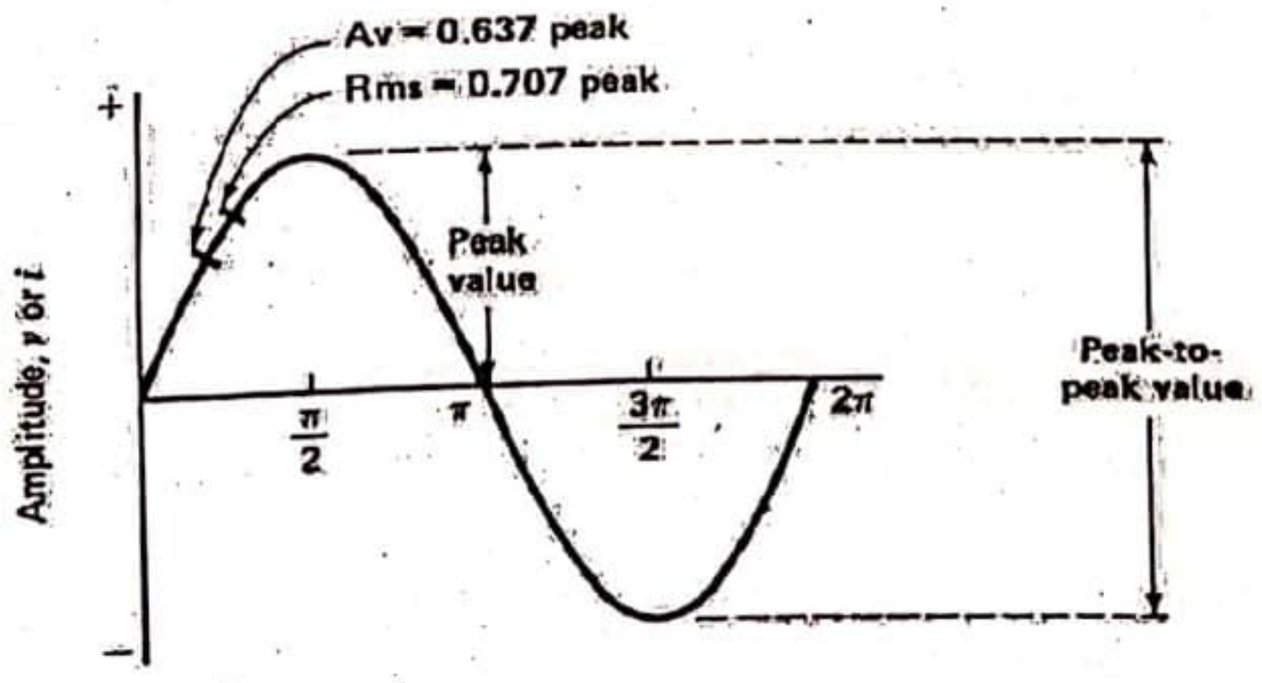
Root mean square (rms) value:-

It is the square root of the average of squared instantaneous values of voltage or current in a period.

$$V_{rms} = V_o/\sqrt{2} = 0.707V_o$$

$$I_{rms} = I_o/\sqrt{2} = 0.707I_o$$

rms value is also called effective value.



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POINT TO PONDER

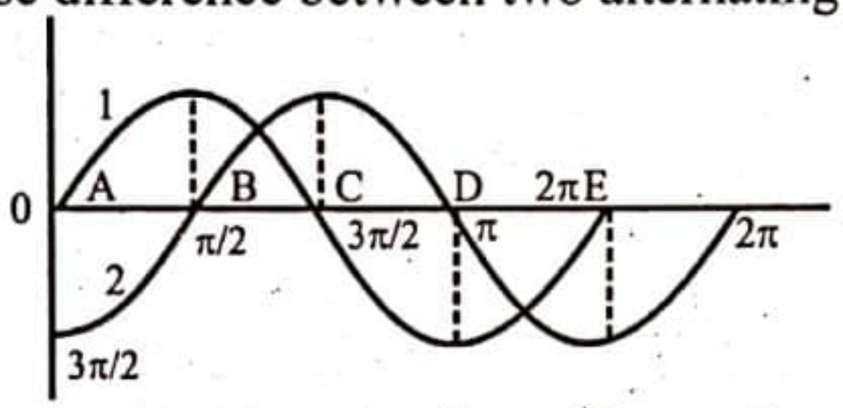
The average value of a sinusoidal symmetrical signal is zero over a cycle but RMS value is not. That is why practically all the calculations are based on RMS value.

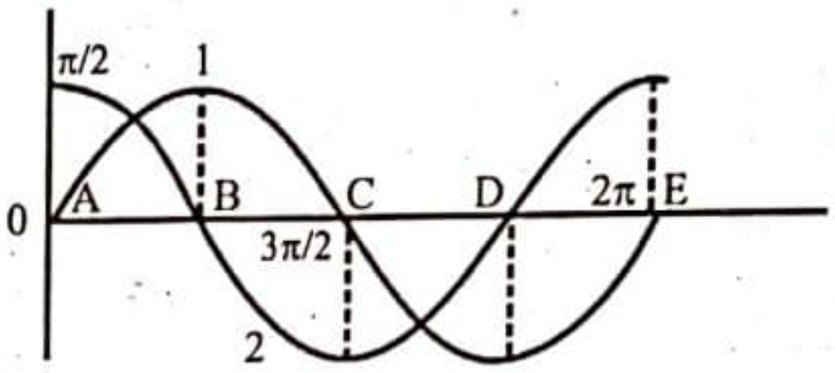
Phase

The angle θ which specifies the instantaneous value of alternating voltage or current is known as its phase.

Phase Lag and Phase lead

The phase difference between two alternating qualities is shown in figure.





- Phase lag occurs when the phase of waveform 2 is less than the phase of waveform 1.
- Phase lead occurs when the phase of waveform 2 is greater than the phase of waveform 1.

Representing Phases and Alternating Quantities by Vectors

Projection of a counter **clockwise rotating vector** along represents a **sinusoidally alternating** voltage or current.

Vector Diagram

A set of counter clockwise rotating vectors whose lengths represents the peak values or rms value of the signals and the angle between them represents the change of phase in AC signals is collectively called as vector diagram.

D.C CIRCUIT

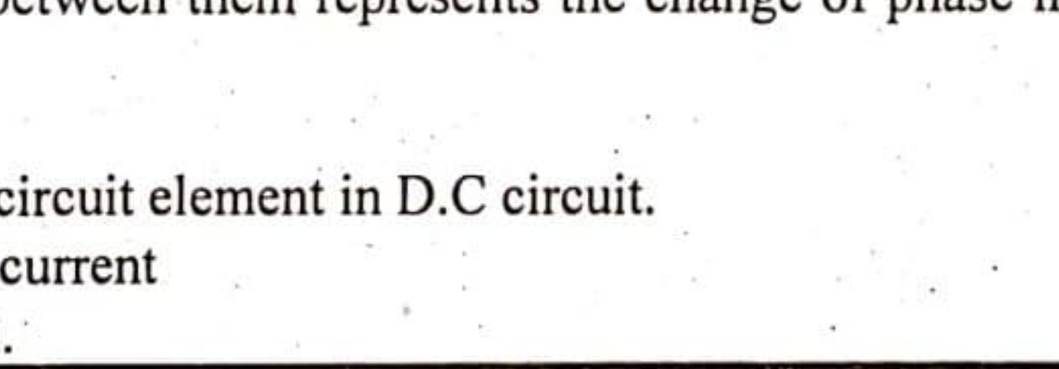
- Resistor R is the basic circuit element in D.C circuit.
- R controls voltage and current
- Ohm's law can be used.

A.C CIRCUIT

- Resistor (—∧∧∧∧∧—) inductor (—∿∿∿∿—) & capacitor (—| |—) These are three main components of a AC circuit:-

A.C THROUGH RESISTOR

- Through resistor, $V = V_o \sin\omega t$ and $I = I_o \sin\omega t$ **voltage and current are in** phase.
- If one increases or decreases, the other **does the same.**
- $P = VI = I^2R = V^2/R$, holds true only when V & I are in phase.



A.C THROUGH CAPACITOR

- **Due to D.C, a capacitor behaves as insulator. It only stores charge.**
- Due to A.C, a capacitor behaves as conductor.
- Through capacitor, charge on parallel plates of a capacitor,

$$q = CV_o \sin\omega t = q_o \sin(\omega t)$$

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- Current leads voltage by phase $\theta = 90^\circ$ or $\pi/2$
- A.C can pass through capacitor (seems passing) because of the continuously reversing polarity.
- Reactance = measure of opposition of capacitance against flow of A.C.
- Reactance is measured in ohms

$$X_c = \frac{V_{rms}}{I_{rms}} = \frac{1}{2\pi fC} = \frac{1}{\omega C}$$

- As frequency increases Xc decreases.
- Voltage lags current by 90° in a pure capacitive circuit

A.C THROUGH INDUCTOR

- Through inductor, A.C produces self-inductive effects because it constantly changes.
- When potential difference is applied back emf is produced.

$$\epsilon_L = \frac{L\Delta I}{\Delta t}, \quad V = \frac{L\Delta I}{\Delta t}$$

- Current **lags behind** voltage by 90° or $\pi/2$.
- Inductive reactance is measure of opposition offered by the inductor coil to the flow of A.C through it.

$$X_L = \frac{V_{rms}}{I_{rms}} = 2\pi fC = \omega C$$

$$X_L = V/I = 2\pi fL = \omega L$$

- As frequency increases X_L increases
- In a pure inductor, energy gained = energy given out
- No power loss in pure inductive or capacitive circuit takes place.

Current lags voltage by 90° in inductive circuit.

IMPEDANCE (Z)

Combined effect of resistance R, capacitive reactance X_c & inductive reactance X_L in a circuit in which A.C is **provided is called impedance.**

$$Z = \frac{V_{rms}}{I_{rms}}$$

Impedance is measured in ohms.

Circuit Element(s)	Impedance (Ω)	Phase Angle (ϕ)
R	$Z = R$	0°
L	$Z = X_L = \omega L$	+90°
C	$Z = X_C = 1/\omega C$	–90°
R L	$Z = \sqrt{R^2 + X_L^2}$	$0^\circ < \phi < 90^\circ$
R C	$Z = \sqrt{R^2 + X_C^2}$	$-90^\circ < \phi < 0^\circ$
R L C	$Z = \sqrt{R^2 + (X_L - X_C)^2}$	$\phi > 0^\circ$ if $X_L > X_C$ $\phi = 0^\circ$ if $X_L = X_C$ (Resonance) $\phi < 0^\circ$ if $X_L < X_C$

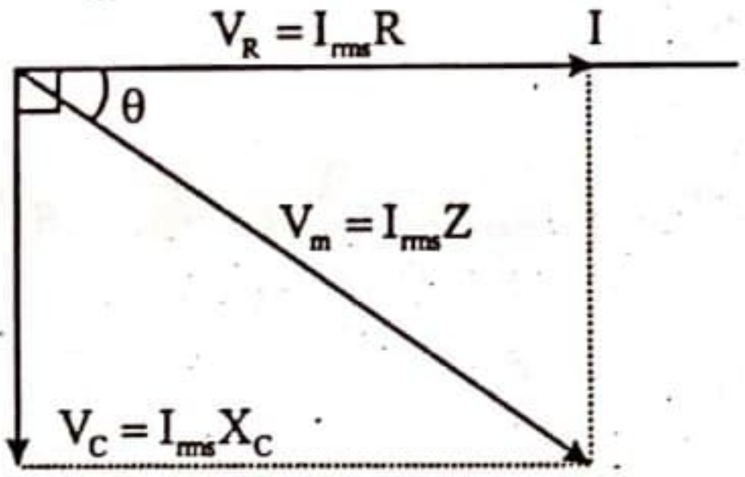
Note: Current vector is taken along X-axis

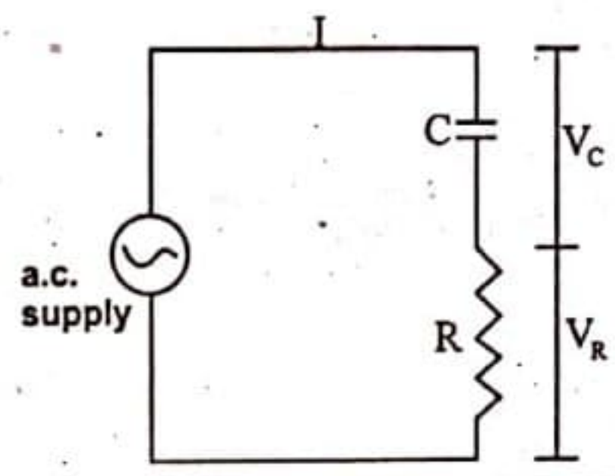
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R-C SERIES CIRCUIT

$$\text{Impedance } Z = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}$$

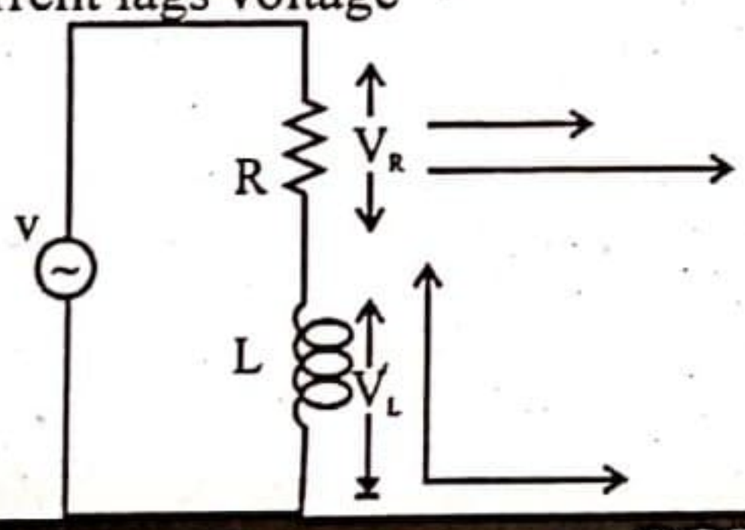
- **Phase between V & I is $\theta = \tan^{-1}(1/\omega CR)$**
- Current leads **voltage.**

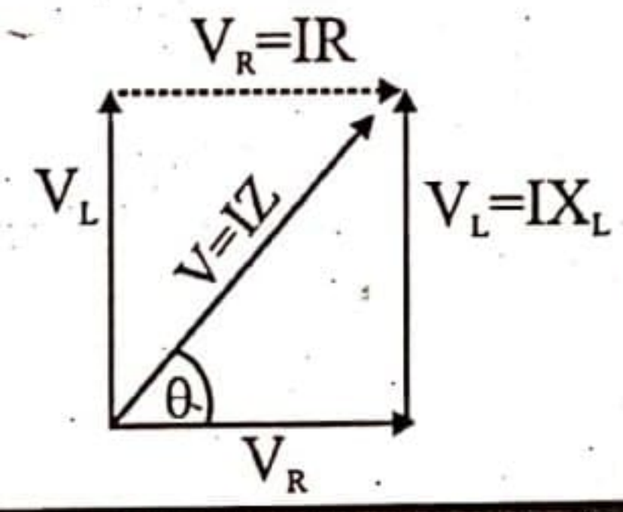


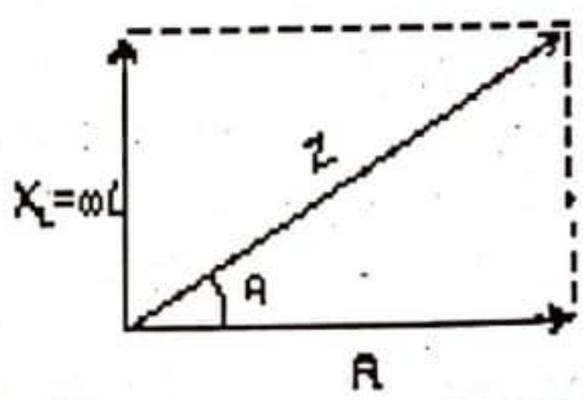


R-L SERIES CIRCUIT

- Impedance $Z = \sqrt{R^2 + (\omega L)^2}$
- **Phase between V & I is $\theta = \tan^{-1}(\omega L/R)$**
- Current lags voltage





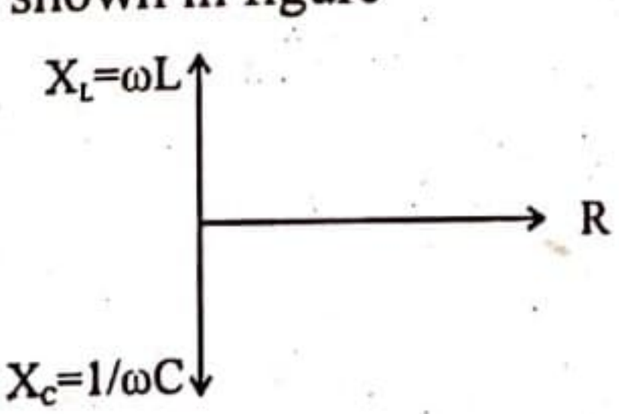


POWER IN A.C CIRCUIT

- Power dissipation = 0, in purely **inductive & capacitive circuit**
- **P = VI only when V & I are in phase in a purely resistive circuit.**
- P = IV cosθ in real L & C circuit where cosθ is power factor & Vcosθ is component voltage vector **along current.**

SERIES RESONANCE CIRCUIT

- $X_L = \omega L$ and $X_C = \frac{1}{\omega C}$
- At low frequency capacitance **dominates** and circuit behave as R-C series circuit and at high frequency inductance **dominates and circuit behave as R-L series circuit.**
- The impedance diagram is shown in figure

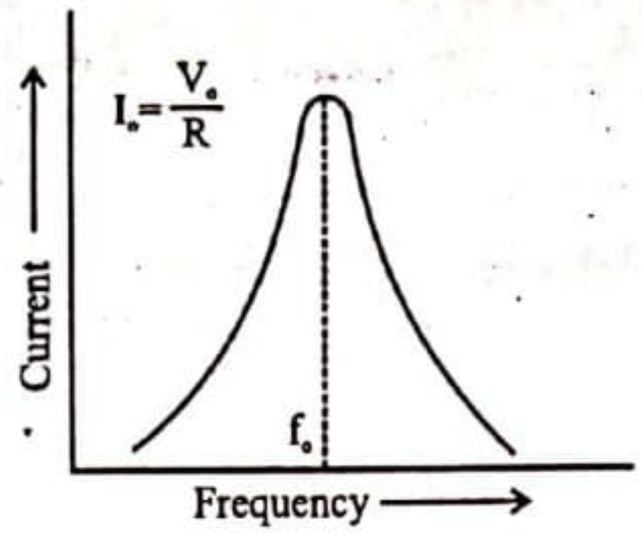


- If $X_L = Xc$, then it is 'resonance' and frequency at this time is called **resonance** frequency.

$$\omega_r L = 1/\omega_r C$$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

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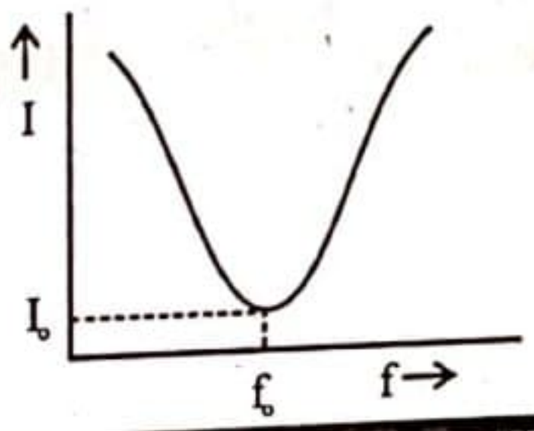
- At resonance, impedance is minimum and is equal to R.
- At resonance V_L, the voltage drop across inductance and V_C the voltage drop across capacitance may be much larger than the source voltage.

PARALLEL RESONANCE CIRCUIT

- The resonance frequency is

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

- At resonance the impedance is maximum. Hence current is minimum at resonance and **in phase** with voltage.
- At resonance branch currents may be larger than source currents.
- At resonance power factor is one



THREE PHASE A.C SUPPLY

- In three phase A.C generator, there are three coils inclined at **120° angle** to each other.
- Each coil is connected to its own **pair of slip** rings.
- In three-phase supply, total load is divided in three parts.
- There will be no drop of voltage supply in three phases.
- Three-phase supply can provide 400V between two lines.
- The line to neutral voltage is 230V.
- Star type connection is used to connect three phase wires and one neutral wire.

PRINCIPLE OF METAL DETECTOR

- Coil (L) & Capacitor (C) are coupled to produce **oscillations of currents.**
- L-C circuit behaves like an oscillating **mass spring system.**
- Energy oscillates between a capacitor and inductor called an electrical oscillator.
- L-C circuit produce **beats phenomenon** for metal detection.

CHOKE

- It is an inductive coil.
- It consumes extremely **small power.**
- It is used in A.C circuit to limit current.

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ELECTROMAGNETIC WAVES (EMW)

- Electromagnetic waves were predicted by Maxwell and experimentally produced by **Frank Hertz.**
- Electromagnetic waves are **oscillating electric and magnetic fields**
- Changing magnetic flux produces electric field given by;

$$E = \left(\frac{1}{2\pi r}\right)\frac{\Delta\phi_m}{\Delta t}$$

- Changing electric flux produces magnetic field given by; $B = \left[\frac{\mu_o \in_o}{2\pi r}\right]\frac{\Delta\phi_e}{\Delta t}$
- Speed of e.m waves in vacuum is given by $v = \frac{1}{\sqrt{\mu_o \in_o}} = 3x10^8\ m\ s^{-1}$
- The frequency is about **10^6Hz depending upon wavelengths.**

PRODUCTION OF E.M WAVES

- E.M waves in laboratory are produced by **oscillation of electrons.**
- Frequency of oscillatory circuit is $f = \frac{1}{2\pi\sqrt{LC}}$

RECEPTION OF E.M WAVES

The reception of EMW is based on a LC circuit in which the value of inductance is fixed but varying capacitance gives different frequencies.

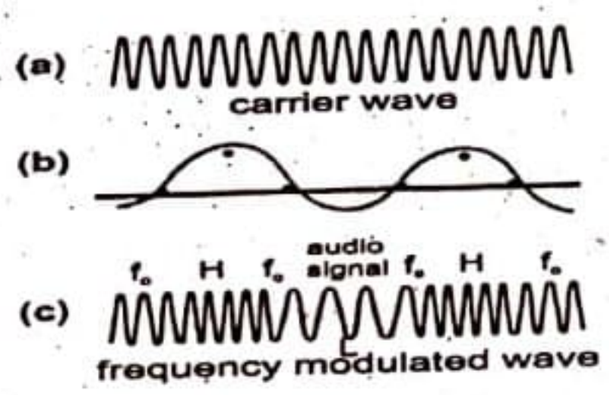
MODULATION

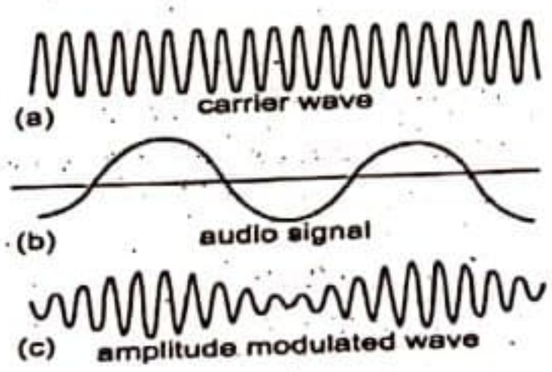
The process of mixing the low frequency signal (sound) with high frequency radio waves is called **modulation.**

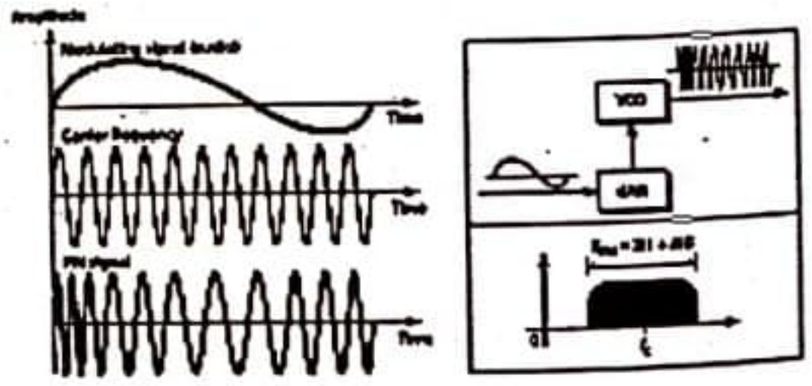
The resultant wave is called **modulated wave.**

Types

- ✦ Amplitude modulation (A.M)
- ✦ Frequency modulation (F.M)
- ✦ Phase modulation. (P.M)







Phase modulated wave

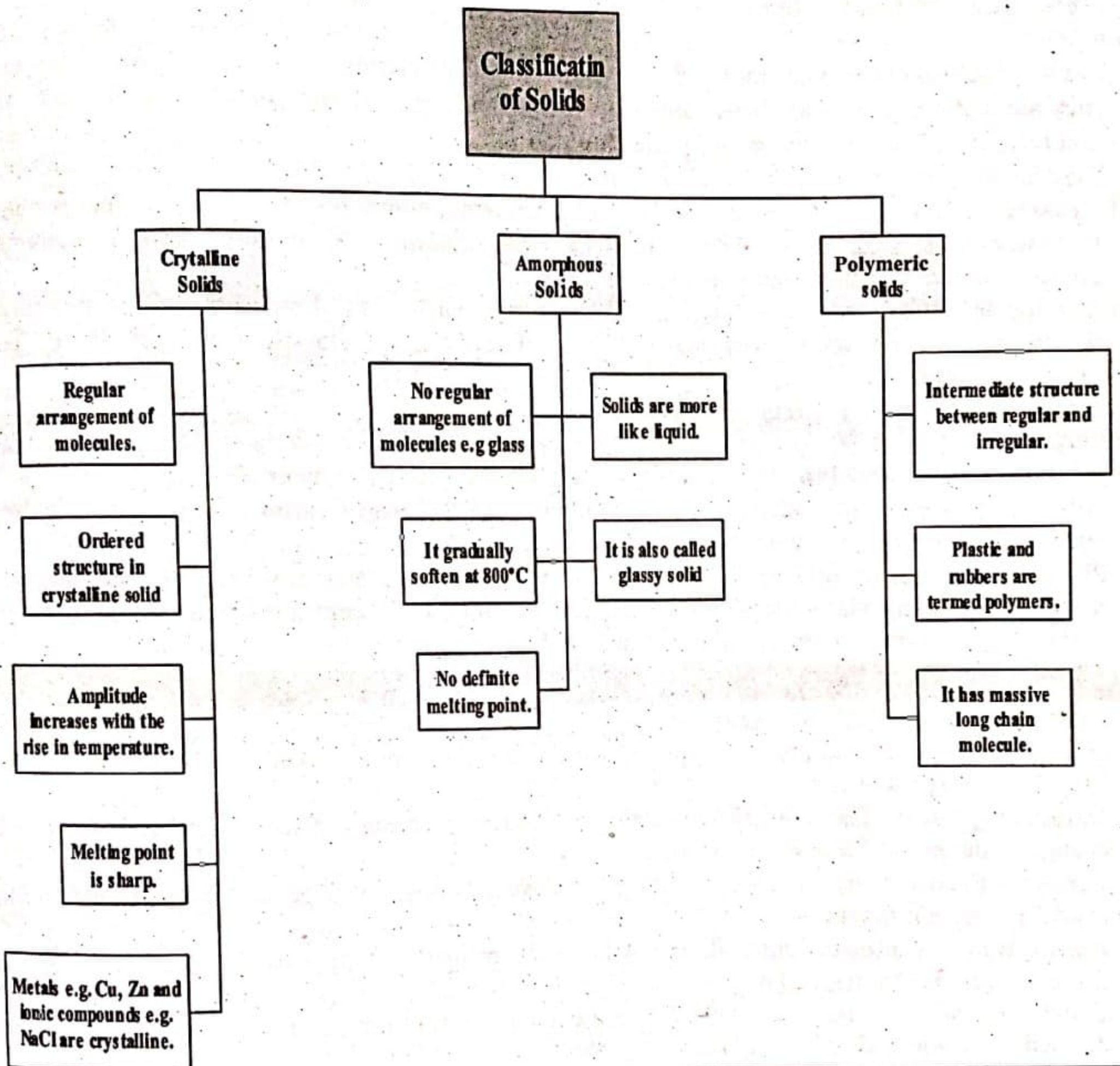
- Modulated waves are demodulated by receiving sets (TV or radio set), rectified and then detected.
- Detection of modulated wave takes place only when frequency of tuning circuit equals to that of transmitting circuit and **hence electrical resonance is produced.**

POINT TO PONDER

- Frequency range of A.M signal 540KHz to 1600KHz
- Frequency Range of F.M signal 88MHz to 108MHz
- F.M signal does not contain any noise signal as the A.M does.

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17 CHAPTER PHYSICS OF SOLIDS



SOLIDS

All solids are made up of atoms and molecules but due to their different internal arrangement of the molecules inside them, they are different classes:

(i) **Crystalline Solids:** The solids in which the atoms are arranged in a definite, regular and long range order are said to be crystalline.

Example: Quartz, mica, sugar, copper Sulphate, sodium chloride etc.

Properties:

- They have long range symmetry, i.e., regular arrangement is extended over a large volume of the crystal.
- They possess uniform chemical composition.

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- The physical properties like thermal conductivity, electrical conductivity, compressibility, refractive index etc, have different values in different directions.
- They have flat surface.

(ii) **Amorphous Solids:** The solids in which the atoms are arranged in indefinite, irregular and short range order are said to be amorphous.

Example: Glass, rubber, sulphur etc.

Properties:

- The distribution of atoms or molecules in these solids is random.
- They are isotropic, i.e., they have same physical properties in all directions.
- Amorphous solids do not have sharp melting points.
- They have no characteristic geometrical shape.

(iii) **Crystal Lattice:** A crystal structure is a periodic arrangement of points in space and is obtained by associating with every lattice point a unit assembly or basis of atoms, identical in composition, arrangement and orientation.

(iv) **Polymeric Solids:** Polymers may be said to be more or less solid materials with a structure that is intermediate between order and disorder. They can be classified as partially or poorly crystalline solids.

Example: Polythene, polystyrene and nylon etc.

Properties:

- Polymers form a large group of naturally occurring and synthetic materials.
- Polymers consist wholly or in part of chemical combinations of carbon with oxygen, hydrogen, nitrogen and other metallic or non-metallic elements.
- Plastics and synthetic rubbers are termed 'Polymers' because they are formed by polymerization reactions in which relatively simple molecules are chemically combined into massive long chain molecules, or "three dimensional" structures.

ELASTICITY

- **Elasticity:** When external forces are applied on a body, which is not free to move, there is a change in its length, volume or shape. When these forces are removed, the body tends to regain its original shape and size.
- **Deforming Force:** The external force acting on a body on account of which its size or shape or both changes is defined as the deforming force.
- **Perfectly Elastic Body:** If a body completely recovers its original shape and size, it is called perfectly elastic. Example is quartz.
- **Plastic Body:** The body which does not have the property of opposing the external deforming force, is known as a plastic body.

  The bodies which remain in deformed state ever after removal of the deforming forces, are defined as plastic bodies. Wet clay is example of plastic body.

Note: Actually, no body is perfectly elastic or perfectly plastic. All bodies behave in between two limits. We may consider quartz as almost perfectly elastic and putty or wet clay as almost perfectly plastic.

STRESS

- The internal restoring force acting per unit area of a deformed body is called stress.
- Since in equilibrium, the magnitude of the external force is equal to the restoring force, the stress in equilibrium is measured by the external force per unit area.
- If a force F is applied on area A, in equilibrium Stress = F/A.
- The stress developed in a body depends upon the way in which external force is applied on the body.
- Unit of stress is $N\ m^{-2}$ and its dimension is $\left[ML^{-1}T^{-2}\right]$

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- Depending upon, how the external forces are applied on a body, the stress is of three types.
  (a) Longitudinal stress **(b)** Volume stress **(c)** Tangential or shearing stress

(a) Longitudinal Stress

- When the stress is normal to the surface of the body, then it is known as longitudinal stress.
- This type of stress is produced due to deformation in length or volume of the body.
- Longitudinal stress is of two types: **(i)** Tensile stress **(ii)** Compression stress
- The longitudinal stress produced due to increase in length or volume of a body is defined as tensile strength.
- The longitudinal stress, produced due to decrease in length or volume of a body, is defined as compression stress.

(b) Volume Stress

- If equal normal forces are applied on every surface of a body, then it undergoes change in volume. The force opposing this change in volume per unit area of cross-section is defined as volume stress.
- It is numerically equal to the applied external force per unit area of cross-section and acts outwards.

(c) Shear Stress

- When the stress is tangential or parallel to the surface of a body, then it is known as shear stress.
- Due to this stress, the shape of the body changes or it get twisted.

STRAIN

When deforming forces are applied on a body it undergoes a change in shape or size. The fractional (or relative) change in shape or size is called the strain. That is,

$$\text{Strain} = \frac{\text{Change in dimension}}{\text{Original dimension}}$$

- The form of strain depends upon the directions of applied force.
- Strain is ratio, hence it has no unit and no dimension.
- Depending upon the way, the deforming forces are applied on a body, strain is of three types.

(a) Longitudinal (linear) strain

- It is the ratio of change in length (Δl) to the original length (l).

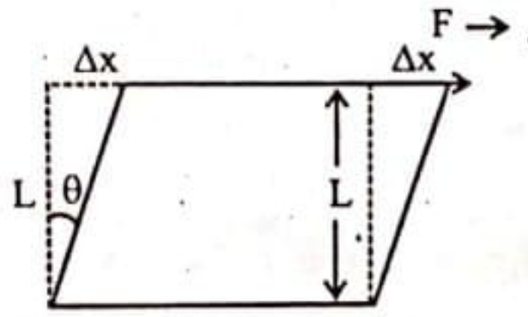
$$\text{Strain} = \frac{\text{Change in length}}{\text{Its original length}}$$

(b) Volume strain

- It is the ratio of the change in volume (ΔV) to the original volume (V). $\text{Volume strain} = \frac{\Delta V}{V}$

(c) Shearing strain

- The angular deformation (θ) in radians is called shearing strain. Since θ is small, we may write. Shearing strain $= \theta = \tan\theta = \frac{\Delta x}{L}$



TYPES OF MODULUS OF ELASTICITY

YOUNG'S MODULUS	BULK MODULUS	SHEAR MODULUS
• The ratio of the longitudinal stress to the linear strain is called Young's modulus Y, of the material	• The ratio of normal stress (pressure) to the volume strain is called bulk modulus K.	• The ratio of the shearing stress to the shearing strain is called the modulus of rigidity η, of the material.
• $Y = \frac{\text{Linear stress}}{\text{Longitudinal strain}}$	• $K = \frac{\text{Volume stress}}{\text{Volume strain}}$	• $G = \frac{\text{Shear stress}}{\text{Shear strain}} = \frac{F/A}{\theta}$

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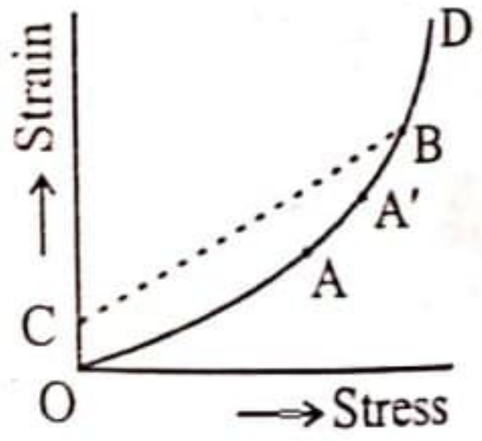
$Y = \frac{FL}{A\Delta L} = \frac{mgL}{\pi r^2 \Delta L}$	$K = \frac{FV}{A(\Delta V)}$	$G = \frac{F}{A\theta}$
• Young's modulus of elasticity is numerically equal to that force which when applied on the wire of the unit cross-section, doubles its length.	• For gases, bulk modulus is of two types **(a)** Isothermal bulk modulus of elasticity. **(b)** Adiabatic bulk modulus of elasticity.	• The concept of shear applies only to solids. The reason is that shear forces are required to deform a solid and the solid tends to return to its original shape when the shear forces are removed.
• Y is the characteristic property of solid materials only.	• The value of K is maximum for solids and minimum for gases.	• Shear modulus does not apply on gases and liquid because gases and liquid do not have a definite shape to return to after deformation.

HOOKE'S LAW

- Within the elastic limits, the stress setup within an elastic body is proportional to the strain to which the body is subjected by the applied external force i.e., Stress x Strain or $\frac{\text{Stress}}{\text{Strain}}$ = a constant. The constant is called modulus of elasticity.
- The value of E depends upon the material of the body and not on the values of stress and strain.
- The values of E, for the same material, are different for different types of strains.
- The value of E depends upon the type of stress and strain produced rather than their values.
- Unit of modulus of elasticity is newton meter^{-2} (N m^{-2}) or pascal.
- Its dimensional formula is $[ML^{-1}T^{-2}]$

ELASTIC LIMIT AND YIELD STRENGTH

- When stress is increased continuously, a point A is reached at which the strain increases more. This point is called **elastic limit.**
- Beyond elastic limit, the material does not return to its original condition when the deforming force is removed. It acquires what is called a **"permanent set".**
- On stressing a point B, is reached at which the material continues to strain without increase in load, i.e., the wire begins to **"flow down"** inspite of the same constant load. This point is called the **"yield point".**
- After a large strain. It reaches the **"breaking point"** D occurs in the material is called **"breaking stress"** or **fracture stress.**



STRAIN ENERGY IN DEFORMED BODIES

- In any type of strain, the work done per unit volume, i.e., potential energy or the strain energy per unit volume

$$U = \frac{1}{2} \times \text{Stress} \times \text{Strain} \quad \text{or} \quad U = \frac{1}{2} \times \text{Young's moudlus} \times (\text{Longitudinal strain})^2 \quad \textbf{or}$$

$$U = \frac{1}{2} \times \text{Bulk modulus} \times (\text{Volume strain})^2 \quad \text{or} \quad U = \frac{1}{2} \times \text{Shear Modulus} \times (\text{Shearing strain})^2$$

ENERGY BANDS THEORY

A solid can be treated as a densely packed system obtained by bringing together isolated single atoms. An isolated single atom possesses a number of discrete energy levels that can be occupied by electros the atom. Generally the electrons exist in the **ground state,** when excited electrons can shift to higher energy levels. Usually only the valence electrons can participate in these excitations.

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- An energy state, which cannot be occupied, is **forbidden gap.**
- The band formed by a series of energy levels containing the valence electrons is known as **valence band.** The valence band may be partially or completely filled up depending upon the nature of the crystal.
- The next higher permitted band is called as the **conduction band.** This band may be empty or partially filled. In conduction band the electrons can move freely.
- Metals have positive temperature coefficient (α_t) of resistance while semiconductors have negative (α_t).

Classification of solids: All solids employed in electrical work may be classified into the following three groups: **(a)** Conductors **(b)** Insulators **(c)** Semiconductors

CONDUCTORS	INSULATORS	SEMICONDUCTORS
• In the case of a conductor, there will be no forbidden energy gap. The conduction and valence energy bands overlap each other. Obviously, the electrons from the valence band can freely enter the conduction energy band. • In conductors, charge carries responsible for the conduction of electricity are **free electrons.** • The electrical conductivity of conductors is of the order of $10^8 \left(\text{ohm} \times \text{metre}\right)^{-1}$. • Metallic conductors have positive temperature coefficient of resistance. • The resistance of conductor increases due to addition of impurities.	• In the case of an insulator, the forbidden energy band is very wide and hence an electron cannot jump across, from the valence energy band to the conduction energy band. Only when a very large amount of energy is supplied, an electron may be able to jumps across the forbidden band. This explains why certain materials which are perfect insulators behave as conductors only at very high temperatures. In the case of diamond, the forbidden energy gap is nearly 6 eV. • In insulators, no free electrons are available for conduction. • In Insulators, the valence band is completely filled while conduction band is completely empty. • The electrical conductivity of insulators is very low in the range 10^{-16} to 10^{-6} $(\text{ohm-m})^{-1}$ • Ionic crystals are insulators. The other examples are glass, wood, paper, mica, diamond, ceramic, plastic etc.	• In the case of semiconductors, the forbidden energy band is comparatively small. For example 0.7eV for (Ge) and 1.1 eV for silicon. In these cases, when a small amount of energy is supplied, the electrons can easily jump across the forbidden energy band and reach the conduction energy band. • Semiconductor has a much smaller energy gap (E_g) between the top of the highest filled band (called **valence band)** and the bottom of the vacant band just above it called the **conduction band.** • The conductivity of semiconductors is of the order of $1(\text{ohm-m})^{-1}$. • The conductivity of semiconductors increase with increase in temperature. • In semiconductors, electrical conduction is due to electrons and holes. • Semiconductors have negative temperature coefficient of resistance. • The resistance of semiconductor decreases due to the addition of impurities. At absolute zero temperature, conduction band is completely empty and the semiconductor behaves as an insulator.

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Types of Semiconductors

N-type semiconductor | P-type semiconductor

N-TYPE SEMICONDUCTOR	P-TYPE SEMICONDUCTOR
• When a small amount of **Pentavalent Impurity** (Examples: Phosphorus, arsenic, antimony etc.) is added to an intrinsic semiconductor, we obtain an N-type extrinsic semiconductor. • In the N-type semiconductor, the number of electrons in the conduction band>number of holes in the valence band. • The impurity atoms in N-type extrinsic semiconductor are called **donor atoms** as they donate an **extra** electron to pure semiconductor or host lattice. • In the N-type semiconductor, electrons are called as **majority charge carriers,** whereas holes are called **minority charge carriers.** • In the N-type semiconductor, the Fermi level shifts towards the conduction band. • There is no charge on N-type semiconductor because it is formed by the combination of free negatively charged electrons and fixed majority carrier.	• When a small amount or **trivalent Impurity** (Examples: gallium, indium, boron, etc.) is added to an intrinsic semiconductor, we obtain a P-type extrinsic semiconductor. • The impurity atoms in P-type extrinsic semiconductor are called acceptor atoms, as they accept an electron from the host lattice. • In the P-type semiconductor, the number of holes in the valence band > number of electrons in the conduction band. • In the P-type semiconductor **holes are majority charge carriers** while **electrons are minority charge carriers.** • In P-type semiconductor, the Fermi level shifts towards the valence band. • There is no charge on P-type semiconductor also, because it is formed by the combination of free positively charged holes and fixed negatively charged acceptor ions. • The energy levels of the hole can also be calculated approximately using Bohr model.

SUPER CONDUCTORS

- Temperature at which material losses its resistivity and becomes super conductor is called **critical temperature.**
- The first super conductor was discovered in 1911.
- Critical temperature of Al (T_c=1.18 K), tin (T_c=3.72 K), lead (T_c=7.2 K) & Hg(T_c=4.2 K).
- Complex crystalline structure known as yttrium barium copper oxide ($YBa_2Cu_3O_7$) is super conductor at 163 K i.e. at –110°C
- Any superconductor with a critical temperature above 77 K, the boiling point of liquid nitrogen, is referred as a high temperature superconductor.

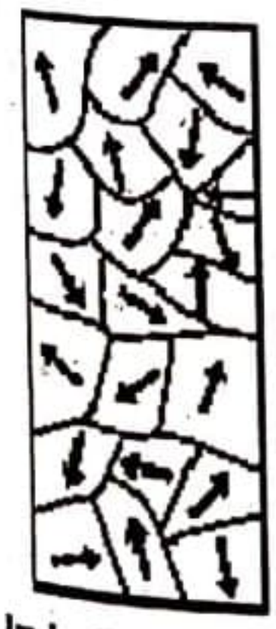
Uses

- ✦ Magnetic resonance **imaging (MRI)**
- ✦ Magnetic **Levitation trains**
- ✦ Powerful but **small electric motors**
- ✦ Faster computer chips
- ✦ Concentrating U^{235} gas in centrifuge system.

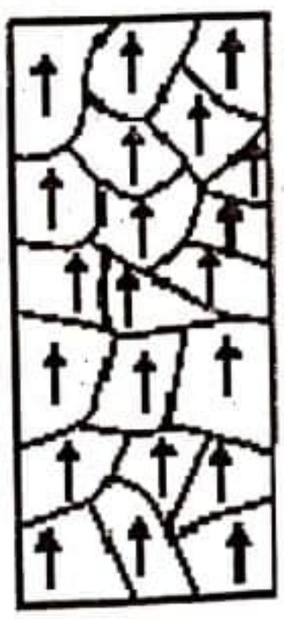
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MAGNETIC PROPERTIES OF SOLIDS

DIAMAGNETISM	PARAMAGNETISM	FERROMAGNETISM
• Diamagnetic substances are feebly repelled by the magnet.	• Paramagnetic substances are feebly attracted by the magnet.	• Ferromagnetic substances are strongly attracted by the magnet.
• Atoms do not have any permanent dipole moment.	• Atoms have permanent dipole moments which are randomly oriented.	• Atoms have permanent dipole moments which are organized in domains.
• Magnetization is small, negative and varies linearly with field.	• Magnetization is small, positive and varies linearly with field.	• Magnetization is very large, positive and varies non-linearly with field.
• Susceptibility is small, negative and temperature independent.	• Susceptibility is small, positive and varies inversely with temperature.	• Susceptibility is very large, positive and temperature dependent.
• Relative permeability μ, is slightly lesser than unity.	• Relative permeability is slightly greater than unity.	• Relative permeability is much greater than unity.
• This property is exhibited by solids, liquids and gases.	• This property is exhibited by solids, liquids and gases.	• The property is exhibited by solids only, that too crystalline.
• It is practically independent of temperature.	• It decreases with rise in temperature.	• It decreases with rise in temperature and above curie temperature becomes para.
• Bi, Cu, Ag, Hg, Pb, water Hydrogen, He, Ne etc are diamagnetic.	• Na, K, Mg, Mn, Al, Cr, Sn and liquid oxygen are paramagnetic.	• Fe, Co, Ni and their alloys are ferromagnetic.

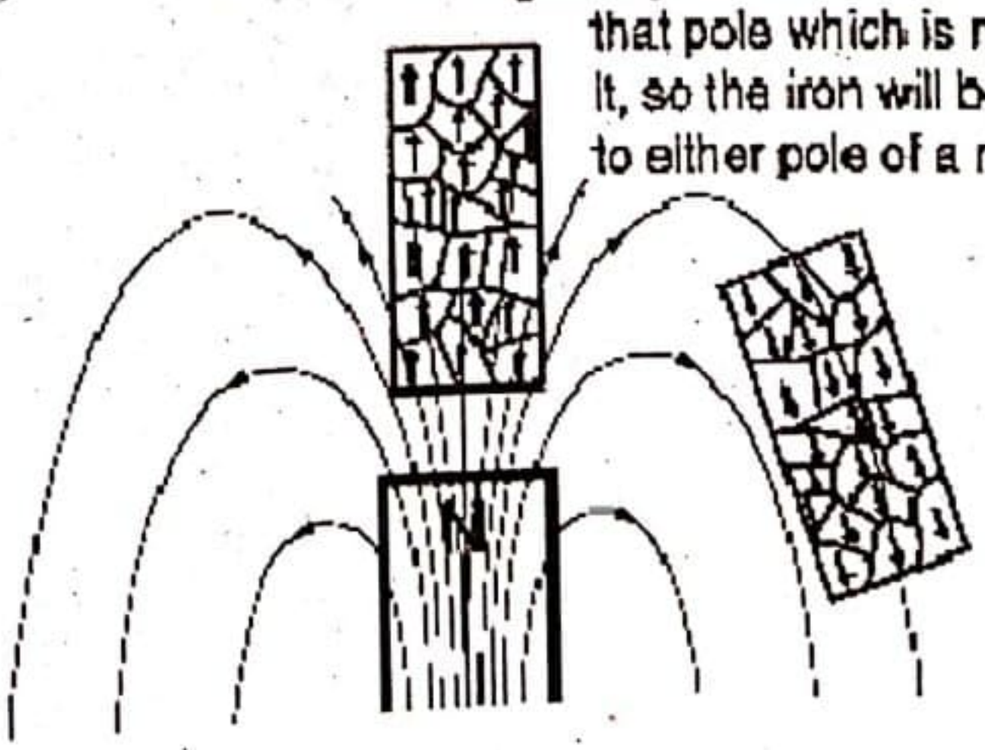


In bulk material the domains usually cancel, leaving the material unmagnetized.



Externally applied magnetic field.

Iron will become magnetized in the direction of any applied magnetic field. This magnetization will produce a magnetic pole in the iron opposite to that pole which is nearest to it, so the iron will be attracted to either pole of a magnet.



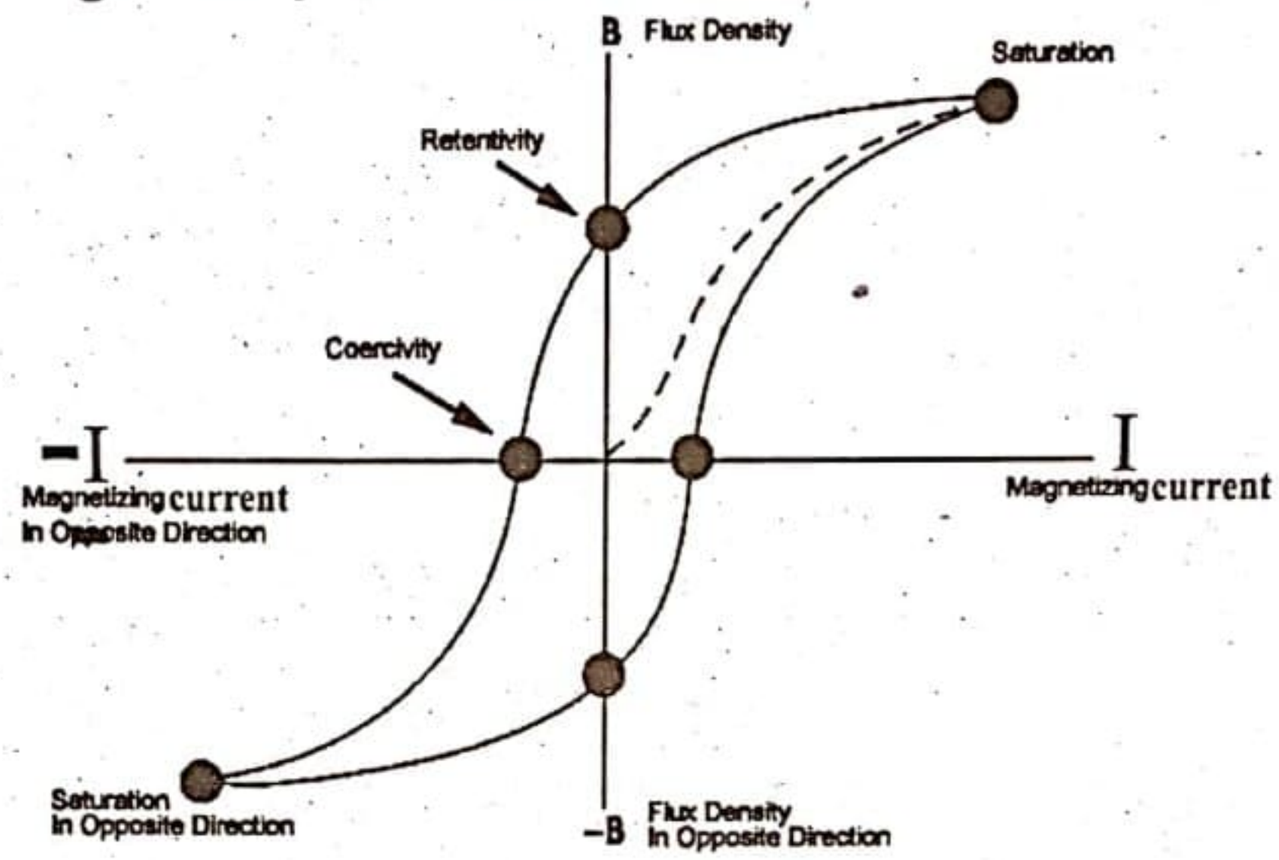
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MAGNETIC HYSTERESIS

The value of flux density for any value of current is always greater when the current is decreasing, than when it is **increasing i.e. magnetism** lags behind **the magnetizing current.**

Saturation

The magnetic flux density increases from zero and reaches a maximum value. At this stage, the material is said to be **magnetically saturated.**



Remanence or Retentivity

When the current is reduced to zero, the material still remains strongly magnetized. It is due to the tendency of domains to stay partly in line, once they have **been aligned.**

Coercivity

To demagnetize the material, the magnetizing current is reversed and increased to reduce the **Magnetization to Zero:** This is known as coercive current.

- Once the material is magnetized, its magnetization curve never passes through the **origin.**
- The Coercivity of steel is more than iron, so it requires more current to demagnetize.

Area of Loop

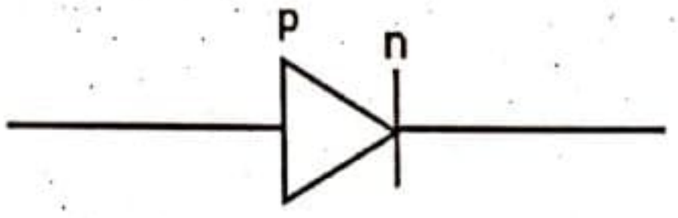
- The area of Hysteresis loop is a measure of the energy needed to magnetize and demagnetize the specimen during each cycle. This is the energy required to do work against internal friction of domains. This work is done against friction, is dissipated as heat. It is called **Hysteresis loss.**
- A material with high retentivity and large coercive force, would be most suitable to make a permanent magnet.

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18 CHAPTER ELECTRONICS

P-N JUNCTION AND ITS CHARACTERISTICS

A p-n junction is formed when a crystal of **germanium** or **silicon** is grown in such a way that if one half of crystal is doped with a **trivalent impurity** and the other half with **pentavalent impurity**



- Its n-region contains free electrons as majority charge carriers and p-region contains holes as majority charge carriers.
- In N-region the minority charge carriers are holes while electrons are minority charge carriers in case of P-region.
- Just after the formation of the junction, the free electrons in the n-region because of their random motion diffuse into p-region. As a result, a charge less region is formed around the junction in which charge carriers are not present. This region is known as depletion region.

POINT TO PONDER

An extrinsic semiconductor i.e. a semiconductor after doping still remains electrically neutral whether it is p-type or n-type

BIASING OF P-N JUNCTION

FORWARD BIASED p-n JUNCTION

When an **external** potential difference is applied across a p-n junction such as p-side is connected with positive and n-side with negative terminals of the battery.

- The external potential difference supplies energy to free electrons and holes in the n-region and p-region respectively. When this energy is sufficient to overcome the **potential barrier**, a current of the order of a few mili-amperes begins to flow across the p-n junction. In this state, p-n junction is said to be **forward biased.**
- If forward bias voltage is increased by ΔV_f, the current increases by ΔI_f. The ratio $\frac{\Delta V_f}{\Delta I_f}$ is known as **forward resistance** of the p-n junction. i.e.

$$r_f = \frac{\Delta V_f}{\Delta I_f}$$

POINT TO PONDER

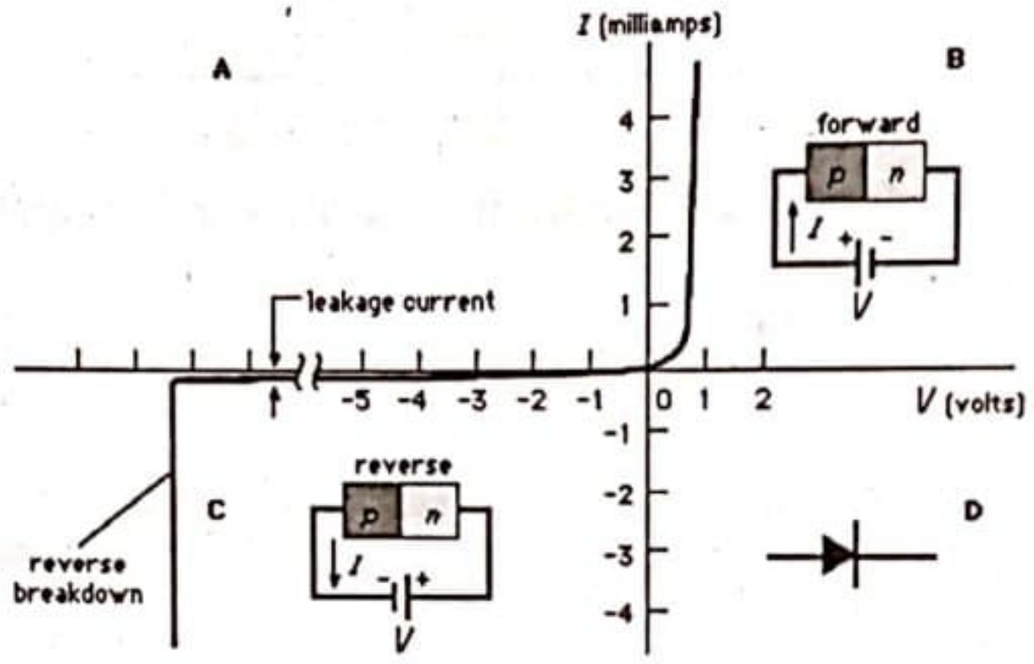
The forward biased barrier potential for Silicon is 0.7V while for Germanium is 0.3V.

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REVERSE BIASED p-n JUNCTION

When the external source of voltage is applied across a p-n junction such that its positive terminal is connected to n-region and its negative terminal to p-region

- In reverse biased situation, no current flows due to the **majority charge carriers.** However a very small current, of the order of few micro amperes, flows across the junction due to flow of minority charge carriers, known as reverse current or leakage current.
- Leakage current increases with increase in voltage.
- At a certain high voltage the reverse current increases sharply. This voltage is called break down voltage.



POINT PONDER

The leakage current for Ge is in amperes while for silicon it is in microamperes.

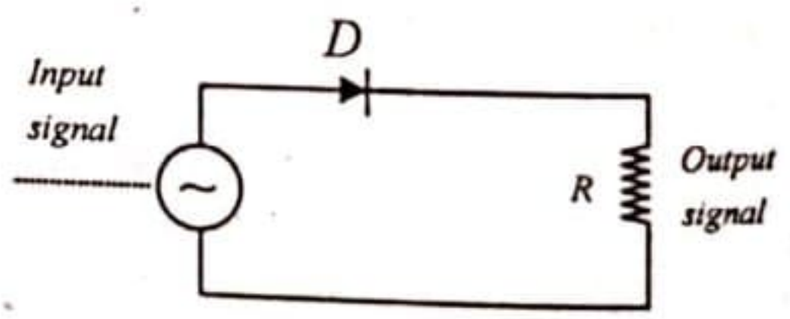
RECTIFICATION

Conversion of alternating current into direct current is called rectification.

- There are two very common types of rectification.

Half-Wave Rectification (HWR)

- One diode is used.
- For upper half or lower half is rectified.
- Can be used for charging battery.



Draw-Backs

- More pulsations in the output wave form.
- Average value of the out put DC signal drops.

Full Wave Rectification (FWR)

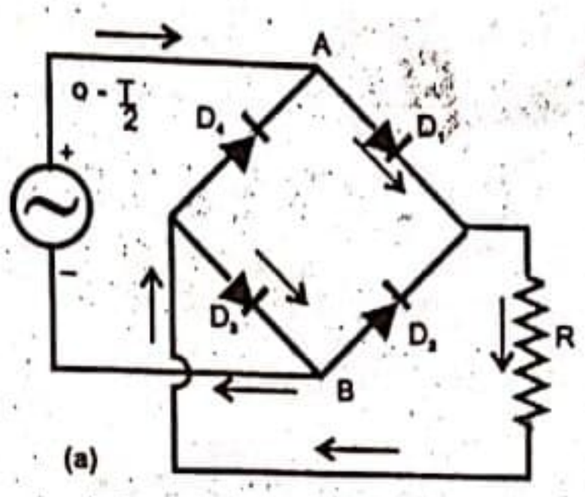
Can be carried out in two ways

- Full Wave Rectification
  - Centre tap transformer with two diodes
  - Ordinary transformer with bridge rectifier circuit employing four diodes

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Bridge Rectifier

- Four diodes are used.
- Two diodes remains ON (FWD Biased) in each half of the input cycle while other two remains off (Reverse Biased) in the same half o the cycle.

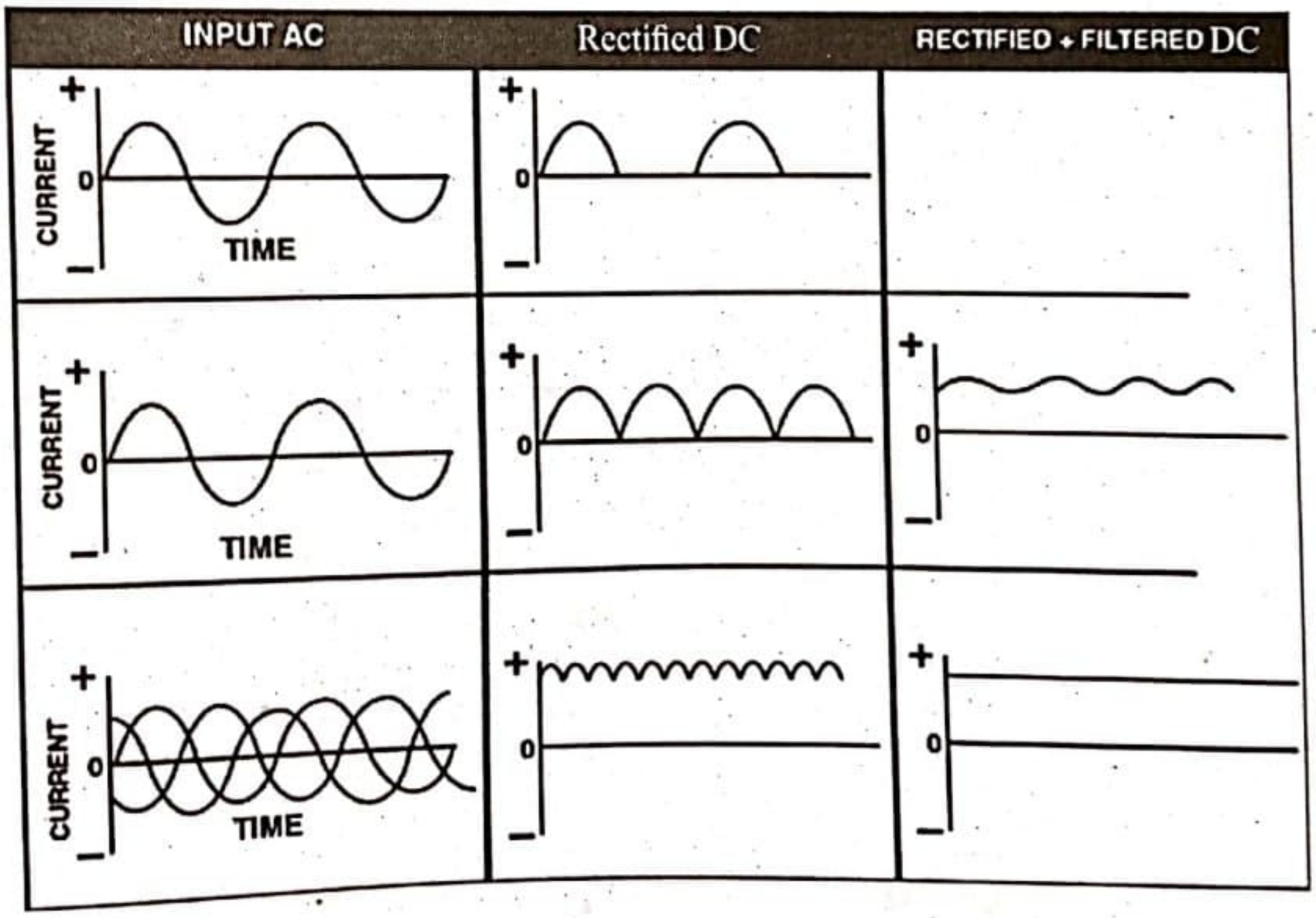


Summary

If input wave has "T" Time period then

O ~ T/2 D_1 & D_3 – **Off and** D_2 & D_4 – **On**

T/2 ~ T D_1 & D_3 – **On** D_2 & D_4 – **Off**



Advantages

- Very inexpensive method of rectification.
- Average values do not drop significantly.
- Lesser pulsations are there in the signal compared to HWR.

POINT TO PONDER

The frequency of the FWR wave is two times the source frequency

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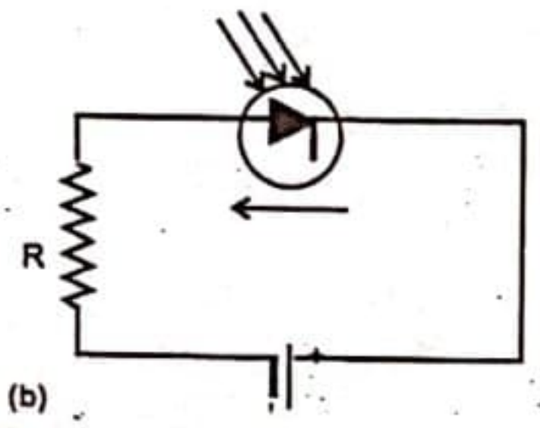
SPECIALLY DESIGNED P-N JUNCTIONS

Light Emitting Diode

- Light emitting diodes (LED) are made from special semi-conductors such as **gallium arsenide** and **gallium arsenide phosphide.**
- When an electron combines with a hole during forward bias conduction, a photon of **visible light is emitted.**
- Convert Electric energy in to light

Photo Diode

- Photo diode is used for **detection of light.**
- A photo diode can turn its current **ON** and **OFF** in nano seconds.
- Photo diode is fastest photo detection device.



POINT TO PONDER

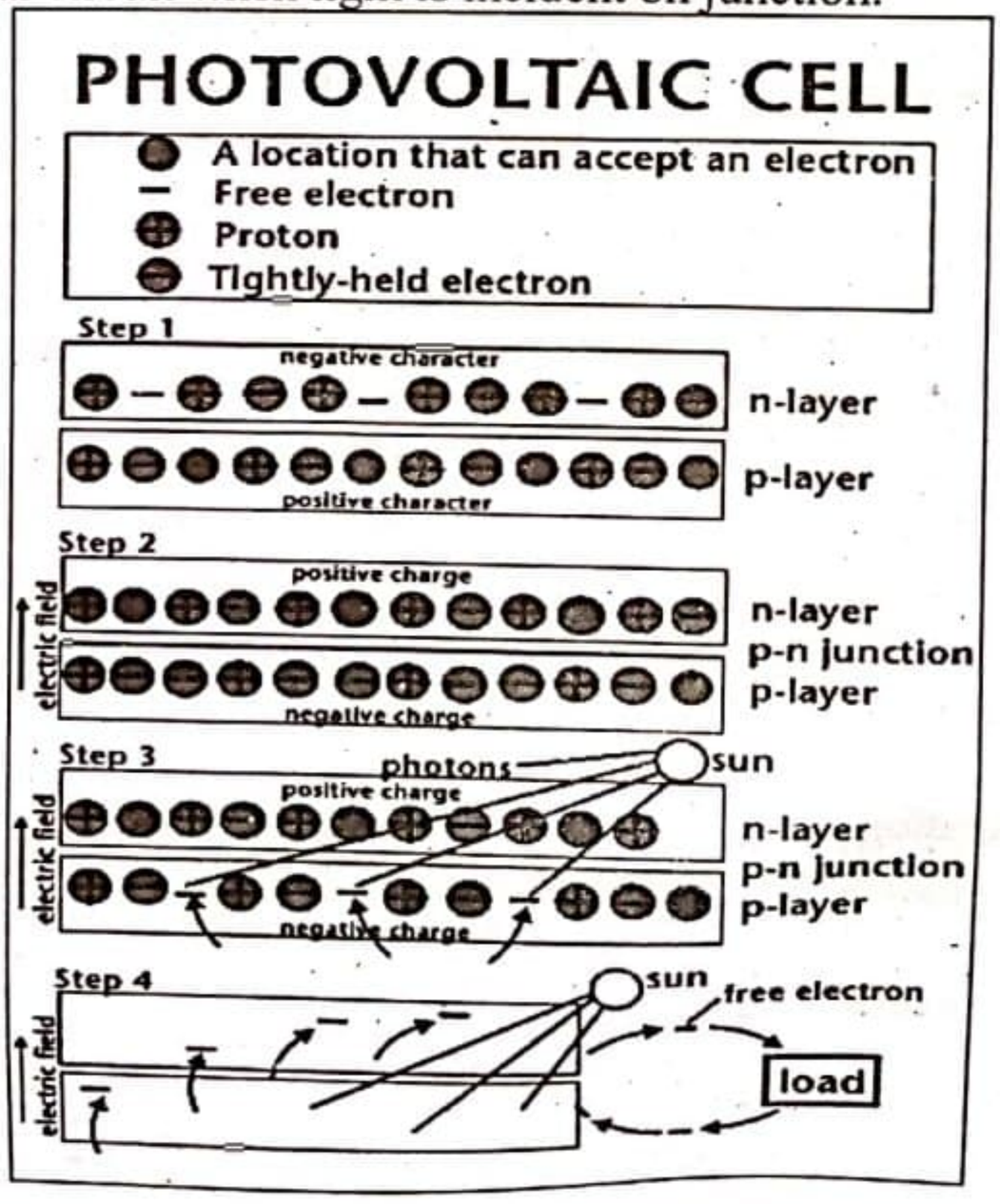
The photo diode is operated in reverse biased region

Applications

(i) Detection of both visible and invisible spectrums
(ii) Automatic switching.
(iii) Logic circuits.
(iv) Optical

Photovoltaic Cell

- Such cells are p-n junction in which potential barrier between p and n regions is used to drive a current through external circuit when light is incident on junction.



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- The current is directly proportional to the intensity of light.
- In order to obtain greater power, series-parallel arrays of thousands of such cells are used forming **photovoltaic panels** and are commonly used in satellites and space stations.

TRANSISTORS

(1) The name of this electronic device is derived from it's fundamental action transfer resistor.

(2) Transistor does not need any heater or hot filament, transistor is small in size and light in weight.

(3) Transistor in general is known as bipolar junction transistor.

(4) Transistor is a current operated device.

(5) It consists of three main regions

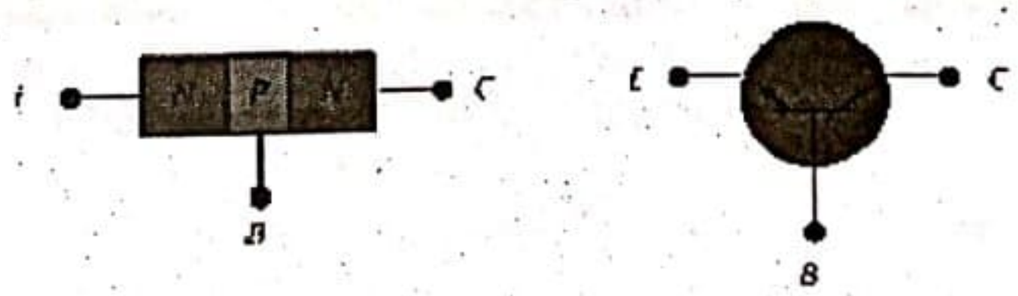
(i) **Emitter (E):** It provides majority charge carriers by which current flows in the transistor. Therefore the emitter semiconductor is heavily doped.

(ii) **Base (B):** The based region is lightly doped and thin.

(iii) **Collector (C):** The size of collector region is larger than the two other regions.

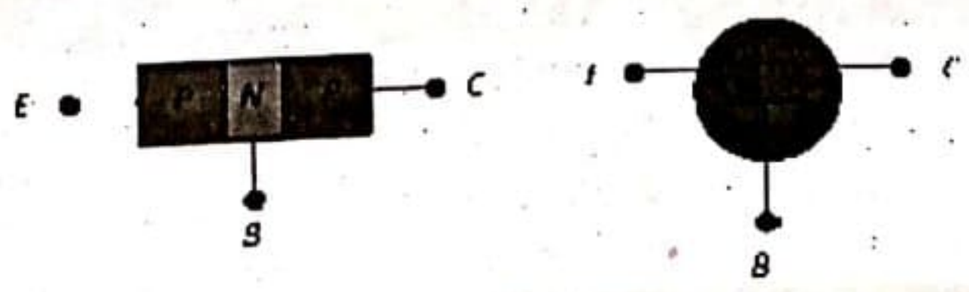
(6) Junction transistor are of two types :

(i) **NPN Transistor:** It is formed by sandwiching a thin layer of P-type semiconductor between two N-type semiconductors



In NPN transistor electrons are majority charge carriers and flow from emitter to base.

(ii) **PNP Transistor:** It is formed by sandwiching a thin layer of N-type semiconductor between two P-type semi-conductors

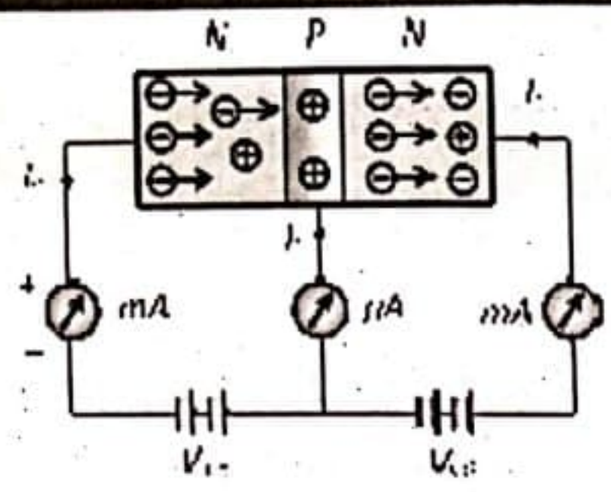
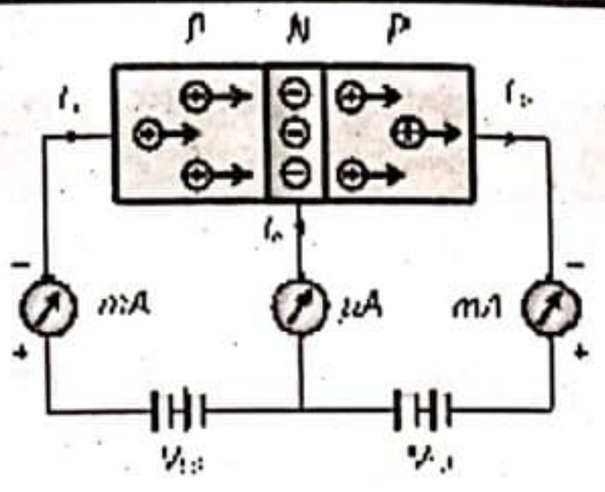
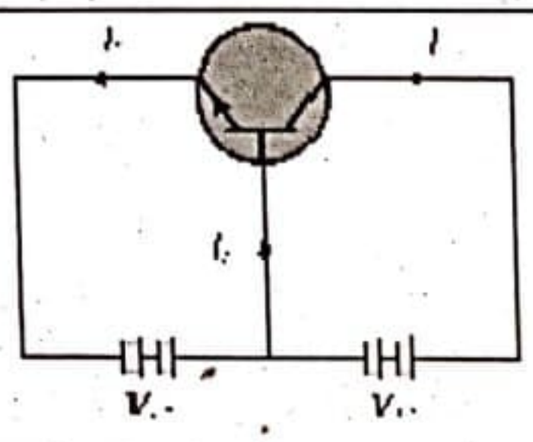
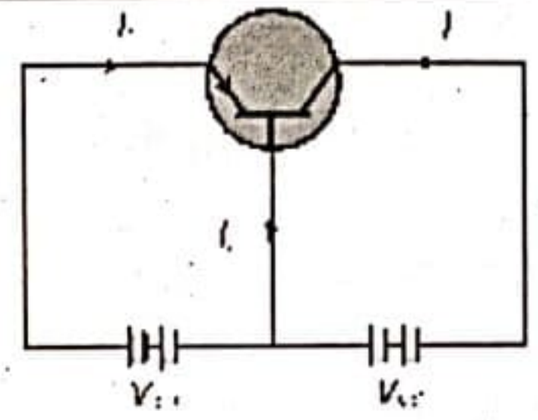


In PNP transistor holes are majority charge carriers and flow from emitter to base.

In the symbols of both NPN and PNP transistor, arrow indicates the direction of conventional current.

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Circuit Diagram of PNP/NPN Transistor

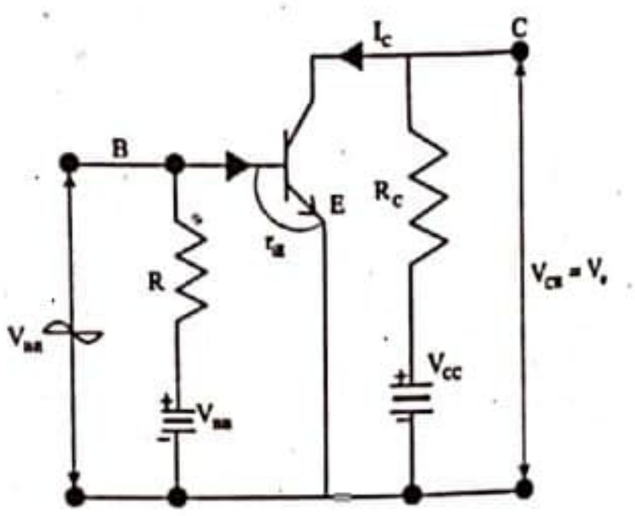
NPN - TRANSISTOR	PNP - TRANSISTOR
	
	
5% emitter electron combine with the holes in the base region resulting in small base current. Remaining 95% electrons enter the collector region.	5% emitter holes combine with the electrons in the base region resulting in small base current. Remaining 95% holes enter the collector region.
$I_E > I_C$, and $I_E = I_B + I_C$	$I_E > I_C$, and $I_E = I_B + I_C$

- $I_E = I_C + I_B$, $I_B << I_C$

Transistor gain of current $(\beta) = \frac{I_C}{I_B}$

TRANSISTOR AS AN AMPLIFIER

- . A junction transistor in the **common emitter** mode can act as a voltage amplifier, if a suitable resistor, called a load is **connected in the collector** circuit.



- $\frac{V_{out}}{V_{in}} = \beta\left(\frac{R_C}{r_{ie}}\right)$

  r_{ie} = in put emitter resistance

- The ratio of $\frac{V_{out}}{V_{in}}$ is called **voltage gain of the amplifier.**

TRANSISTOR AS A SWITCH

- Transistors are used as switches in many important electronic circuits.
- In order to turn on the switch, a large potential V_B is applied between control terminals.
- An electronic computer is basically vast arrangement of electronic switches, which are made from **transistors.**

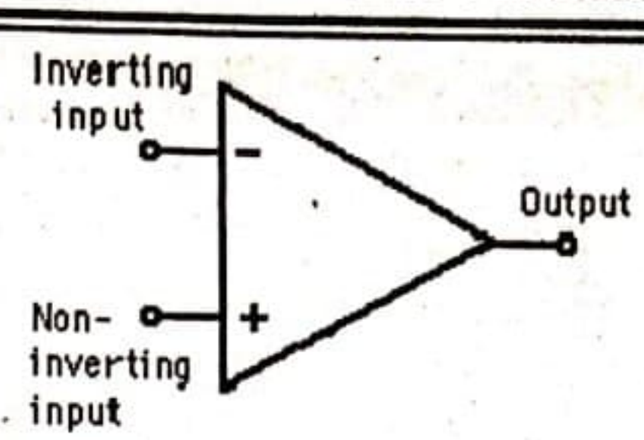
OPERATIONAL AMPLIFIER

- An operational amplifier is so called because it can perform **electronically**.

The term operational amplifier or "op-amp" refers to a class of high-gain DC coupled amplifiers with two inputs and a single output. The modern integrated circuit version is typified by the famous 741 op-amp. Some of the general characteristics of the IC version are:

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- High gain, on the order of a million
- High input impedance, low output impedance
- Used with split supply, usually +/- 15V
- Used with feedback, with gain determined by the feedback network



Characteristics of Operational Amplifier

High Input Resistance

- It is resistance between the (+) and (–) inputs of the amplifier. Its value is very high of the order of several mėga ohms.
- No current flows between two inputs.

Low Output resistance

- It is the resistance between the output terminal and ground.
- Its value is only few ohms

High voltage gain

- It also called open loop gain denoted by A_{OL}

$$Gain = \frac{V_o}{V_+ - V_-} \qquad A_{OL} = \frac{V_o}{V_i}$$

- The open loop gain for amplifier is very high ~10^5.

OP-AMP AS INVERTING AMPLIFIER

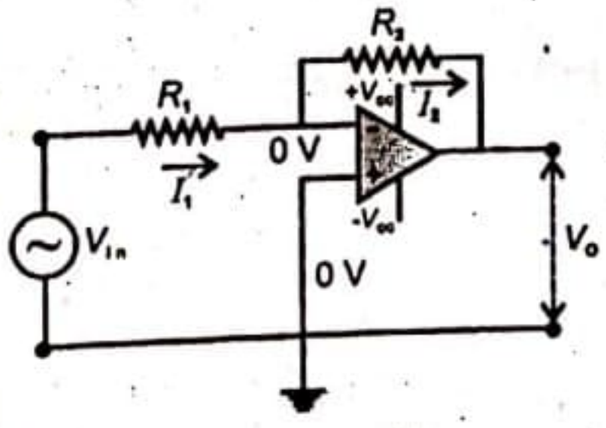
- The non-inverting terminal (+) is grounded; its potential is zero

$$I_1 = \frac{V_i}{R_1} \quad \text{and} \quad I_o = -\frac{V_o}{R^2}$$

- No current flows between (+) and (-) terminals. Therefore, by Kirchhoff's rule.

$$I_1 = I_2$$

$$\frac{V_i}{R_1} = -\frac{V_o}{R_2} \qquad -\frac{R_2}{R_1} = \frac{V_o}{V_i}$$

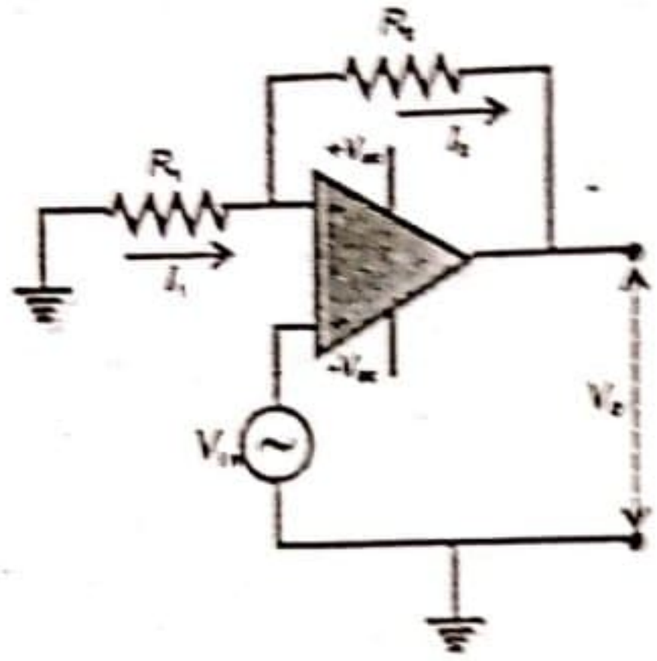


- Signal is inverted
- Gain is defined as the ratio of output voltage to input voltage. $G = -\frac{R_2}{R_1}$

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OP-AMP AS NON-INVERTING AMPLIFIERS

- In this case the input signal V_i is applied at the non-inverting terminal (+).
- Gain = $1+\frac{R_2}{R_1}$



Gain only depends upon values of R_2 and R_1 and is independent of the open loop gain of the OP-AMP.

OP-AMP AS A COMPARATOR

- OP-AMP usually requires two power supplies of equal voltage, but of opposite polarity.
- Most OP-AMP operate with $V_{CC} = \pm 12V$ supply.

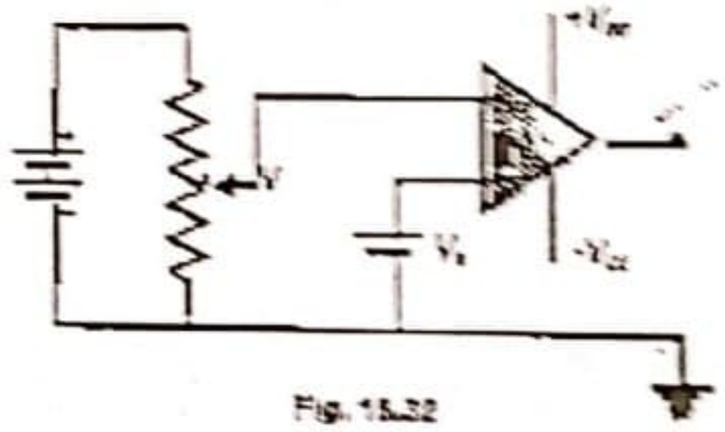


Fig. 18.32

COMPARATOR AS A NIGHT SWITCH

- When intensity of light falls below a certain level, the streetlight is automatically switched on. This can be accomplished by using op-amp as a comparator.

$$V_R = \frac{R_2}{R_1 + R_2} \times V_{CC}$$

LDR is Light Dependent Resistance

$$V' = \frac{R_3}{R_L + R_3} \times V_{CC}$$

V′ provides the voltage to (–) input of OP-AMP.

At Day time, $V' > V_R$

and $V_o = -V_{cc}$

Light switched off

At Night time, $V' < V_R$

$V_o = +V_{cc}$

Light switched on

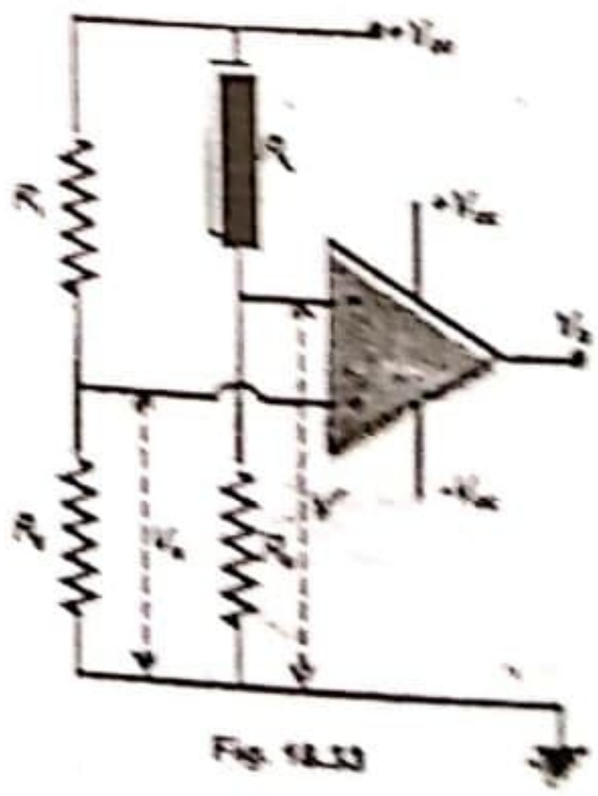


Fig. 18.33

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LOGIC GATES

- Logic gates are building blocks of a digital system. A logic gate is a digital circuit which is based on certain logic relationship between the input and output voltage of the circuit. That is, a logic gate gives an output for various combinations of the inputs. The logic gates are built using the semiconductor diodes and transistors. There are three basic logic gates. They are:

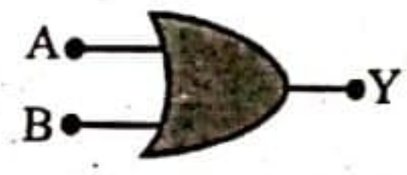
(a)OR gate **(b) AND gate** **(c) NOT gate**

BOOLEAN ALGEBRA

George Boolean developed an **"Algebra of logic"** which is called **"Boolean Algebra'.** The main feature of this algebra is that it permits only two values or states for its variables. These two states may be **"true"** and **"false"** in the logic, **"on"** and **"off"** in electronic circuit but in mathematical way these are **"0"** and **"1"**. Thus each Boolean variable can assume only values 0 or 1.

OR GATE

- OR gate is device that combines A with B to give Y. the OR gate has two (or more) inputs and one output.
- The symbolic representation of a two input OR gate is shown in figure.



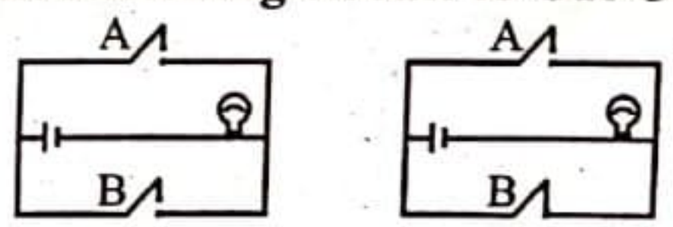
A+B = Y

- These variables A, B and Y have only one of the two values, i.e., either 0 or 1. The OR gate has an output 1 when either A or B or both A and B are 1. Obviously the output would be 0 if both inputs are 0.
- The OR gate in terms of Boolean expression is A + B = Y read as "A OR B equal Y" The meaning of this equation is that Y is true when either A is true or B is true or both are true.
- A table which gives the output states for all possible inputs.

TRUTH TABLE

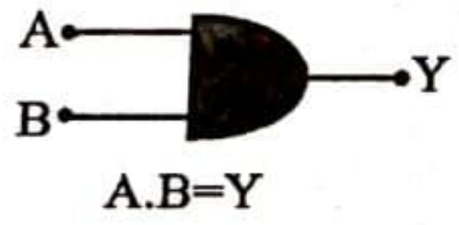
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

Equivalent switching circuit to OR Gate



AND GATE

- The AND gate is circuit which provides an output when all the inputs are simultaneously present.
- The symbolic representation of a two input AND gate is shown in figure.



A.B=Y

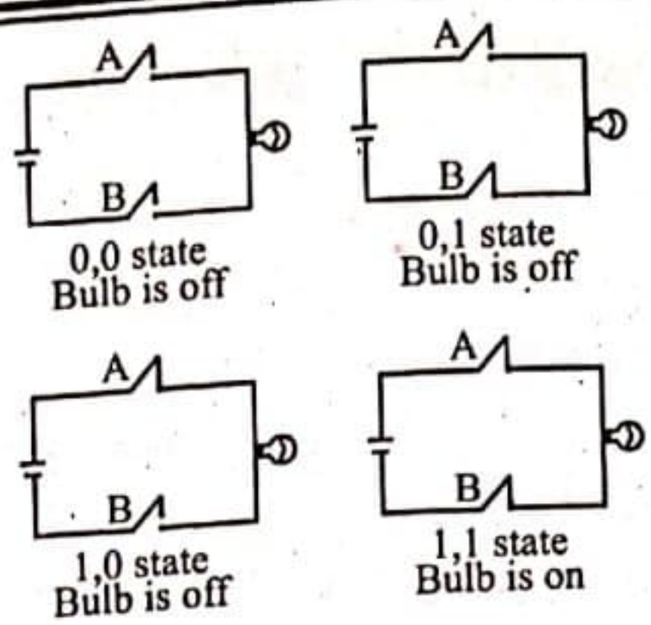
- The AND circuit has two (or more inputs and one output. Here also the two inputs have been marked as A and B while output as Y, A, B and Y are Boolean variables, i.e., having only two values, i.e., either 0 or 1. The AND gate has an output 1 when its both A and B are 1.
- The AND gate in terms of Boolean expression is A.B = Y read as "A AND B equals to Y".
- The logical meaning of this equation is that Y is true when both A and B are true.

Equivalent switching circuit to OR Gate

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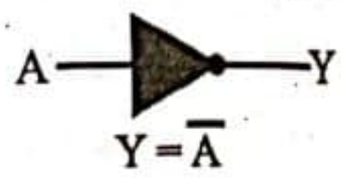
TRUTH TABLE

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1



NOT GATE OR INVERTOR

- The NOT circuit has one input and one output. It is also called NOT gate because output is not the same as its input. It inverts the polarity of the pulse applied to it. Thus NOT circuit negates the input function.
- The symbolic representation of the NOT gate is as shown in figure.
- When A is 0, Y is 1 when A is 1, Y is 0.
- In Boolean algebra, the bar symbol (–) is referred as NOT. The Boolean expression $\overline{A} = Y$ reads "NOT A equals to Y". It implies that Y is negation (or inversion) of A.



TRUTH TABLE

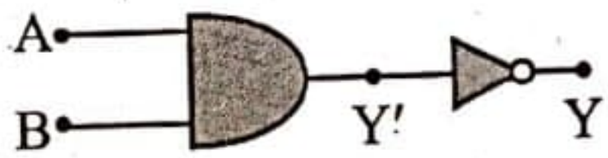
The NOT truth Table

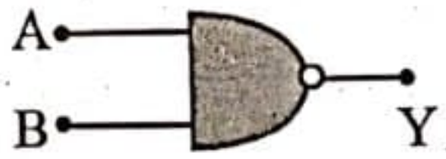
A	Y
0	1
1	0

THE NAND GATE

- It is combination of AND gate and NOT gate. If the output Y' of AND gate is connected to the input of NOT gate, the resulting gate is called NAND gate. The Boolian expression for NAND gate is $Y = \overline{A.B}$

Combination of AND gate and NOT gate			
A	B	$Y' = A.B$	$Y = \overline{A.B} = \overline{Y'}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

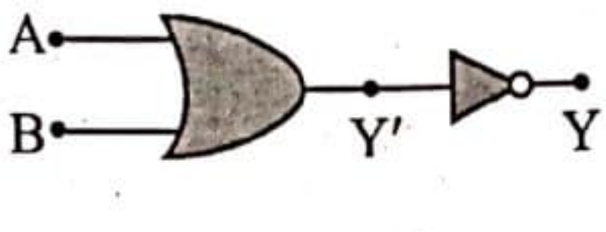


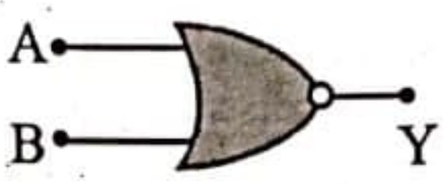


NOR GATE

- The NOR gate is a combination of OR gate and NOT gate. If the output Y' of OR gate is connected to the input NOT gate, the resulting gate is called NOR gate. The Boolian expression for NOR gate is $Y = A + B$

Combination of AND gate and NOT gate			
A	B	$Y' = A + B$	$Y = \overline{A+B} = \overline{Y'}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0





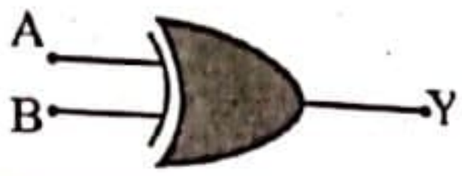
EXCLUSIVE OR GATE (XOR)

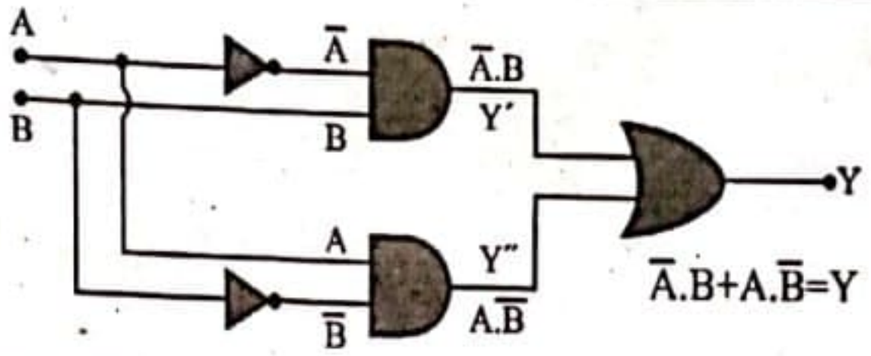
- The output of the exclusive – OR Gate is 1 if its either input, but not both is 1. Which means that when the two input are different (one is 0 and the other 1) the output is 1.

$$Y = \overline{A}.B + A.\overline{B}$$

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Input		Output
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0





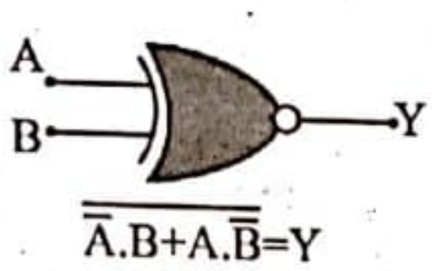
Note: This circuit is also called an "inequality operator or detector because it produces output only when the two inputs are different.

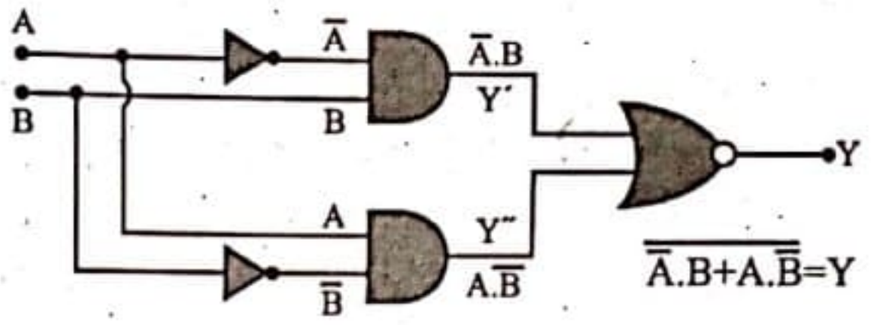
EXCLUSIVE NOR GATE (XNOR)

- The exclusive NOR gate, abbreviated as Ex-NOR, operates exactly opposite to Ex-abbreviated as Ex-NOR, operates exactly opposite to Ex-OR gate

$$Y = \overline{\bar{A}.B + A.\bar{B}}$$

INPUT		OUTPUT
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

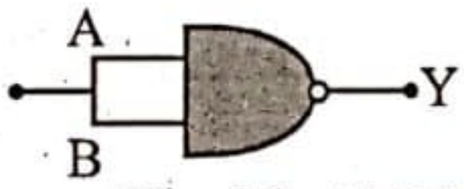




GATE AS BUILDING BLOCK IN DIGITAL CIRCUITS

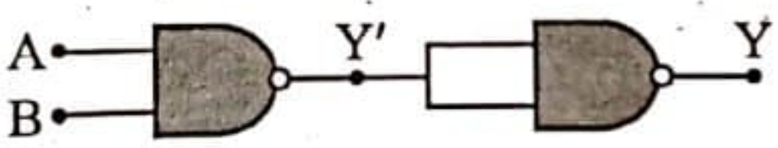
- Repeated use of any of the basic gates (OR, AND and NOT) alone does not produce a different gate. However, the repeated use of NAND (or NOR) gate can produce all the three basic gates. Hence, the NAND (or NOR) serves as a building block in digital circuits.
- **To obtain NOT gate from NAND gate:** When the two inputs A and B of the NAND gate are joined together to make one input, then NAND gate works as NOT gate, using A = B in the truth table of NAND gate we get the truth table of NOT gate.

A	B = A	Y
0	0	1
1	1	0



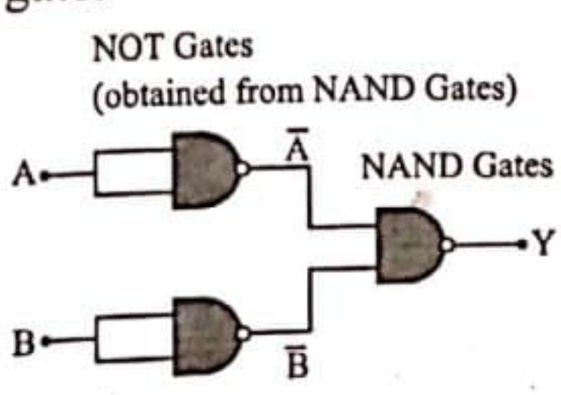
- **To obtain AND gate from NAND gate:** When the output Y′ of the NAND gate in connected to the input of the NOT gate (made from NAND gate by joining its two inputs together), the combination functions as an AND gate. Negation of last column of the truth table of NAND gate gives the truth table of AND gate, provided we read columns A, B and Y only.

A	B	Y′	Y
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1



- **To obtain OR gate from NAND gate:** When the two inputs of a NAND gates are joined together, it works as a NOT gate. Now, if the inputs A and B are inverted by using two NOT gates (obtained from two NAND gates) and the resulting outputs $\bar{A}$ and $\bar{B}$ are fed into a third NAND gate, then the arrangement works as an OR gate.

A	B	$\bar{A}$	$\bar{B}$	Y
0	0	1	1	0
0	1	1	0	1
1	0	0	1	1
1	1	0	0	1

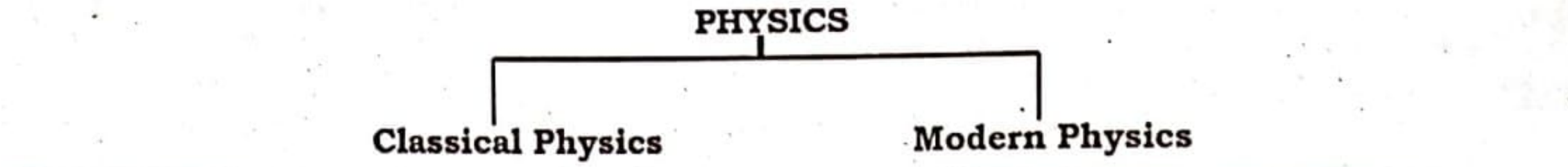


- The construction of the truth table of this arrangement is explained. The columns $\bar{A}$, $\bar{B}$ and Y of this table form the truth table of a NAND gate. The truth table of OR gate is obtained by reading A, B and Y only.

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19 CHAPTER

DAWN OF MODERN PHYSICS



CLASSICAL PHYSICS	MODERN PHYSICS
It is based upon classical mechanics or Newtonian mechanics	It is based upon quantum mechanics
It consists of Newton's laws of motion and other laws dealing at macroscopic level. It deals at ordinary everyday life.	It is a discipline of laws of physics that deals at microscopic level as well as macro levels if car is consider as special case.
Span of classical physics include; **(i)** Newton's three laws of motion. **(ii)** Newton's law of gravitation. **(iii)** Four laws of thermodynamics. **(iv)** Gas laws. **(v)** Maxwell's equation of e.m waves.	Span of modern physics includes; **(i)** Michelson's and Morley's findings. **(ii)** Schiodinger wave equations. **(iii)** De-Broglie hypothesis. **(iv)** Bohr's ideas. **(v)** Heisenberg's uncertainty principle. **(vi)** Plank's theory. **(vii)** Special theory of relativity **(viii)** General theory of relativity.

Ideas of Modern Physics

- Light is an electromagnetic wave
- Light consists of **photons**, each having energy $E = hf$
- Speed of light is a universal constant in vacuum that is independent of motion of source and observers.
- Absorption and emission of electromagnetic waves takes place in the form of packets of energy called **photons.**
- True laws of physics retain their mathematical form in all **inertial frame of reference.**
- All motions and rest are **relative.**
- There is nothing like **absolute rest** or motion.
- Wave - particle duality.
- Reaction takes some time to replay, after action.
- Matter waves are associated with moving particles.
- Einstein Equation's Energy mass relation is $E = mc^2$
- Photon is splitted into a pair of electron and positron, process called **pair production.**
- Positron and electron are **annihilated to photon.**
- Position, momentum, energy and time can't be measured accurately at same time.

RELATIVE MOTION

- The concept of **direction** is purely relative.
- The experiments give same results in same frame of reference. In different frames, give different results.

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FRAME OF REFERENCE

The coordinate system x, y and z axes from where observation is made is called frame of reference.

- **Inertial Fame** is that either it is at rest or moving **with uniform** velocity.
- **Non inertial Frame** is that which is moving with accelerated motion.
- Earth may be considered as an inertial frame of reference for motion on Earth.

POINT TO PONDER

The frame of reference in which the law of inertia is valid is called as inertial frame of reference.

THEORY OF RELATIVITY

- **In 1905,** Einstein put forward his theory of relativity.
- Special theory of relativity deals with inertial frames of reference.

Important Results of Special Theory of Relativity

- $m = \dfrac{m_o}{\sqrt{1-\dfrac{v^2}{c^2}}}$
- $l = l_o\sqrt{1-\dfrac{v^2}{c^2}}$ (Lorentz Contraction)
- $t = \dfrac{t_o}{\sqrt{1-\dfrac{v^2}{c^2}}}$ where v = relativistic speed
- $E = mc^2$
- All motions and rest are relative.
- No body moves with velocity **greater** than velocity of light.

POINT TO PONDER

At ordinary speed (as in common life) the results of special theory of relativity are

$m = m_o$

$\ell = \ell_o$ as $v \approx 0$

$t = t_o$

that is why we don't observe any change in length, mass and time in ordinary life.

NAVSTAR NAVIGATION SYSTEM

- Modern system of navigation satellites called **NAVSTAR** use results of **special theory of relativity.**
- The location and speed anywhere on the Earth can be measured accurate up to 50m after 1hr flight and **2 cm s^{-1}** velocity with use of NAVSTAR.

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BLACK BODY RADIATION

Black body is an ideal **radiator** and ideal **absorber.**

- The emissive or absorptive power is **1.**
- Black body is very bad reflector
- Black body emits electromagnetic waves

Intensity Distribution of Black Body

- **Lummer** and **Pringsheim** measured the intensity of emitted energy of different wavelengths.
- Curve shows the characteristics depending upon temperature.
- At a given temperature, the energy is not uniformly distributed in the **radiation** spectrum.
- $\lambda_{max} x\ T = \text{constant} = 2.9x10^{-3} m\ K$ so, $T \propto \frac{1}{\lambda}$
- The area under the curve shows total amount of energy i.e. **emissive power.**
- Energy (area of curve) is directly proportional to the fourth power of Kelvin temperature i.e. **Stephen- Boltzman law is $E \alpha T^4$**

$$E = \sigma T^4$$

$\sigma = 5.67x10^{-8}\ W\ m^2\ K^{-4}$ = **Stephen's constant**

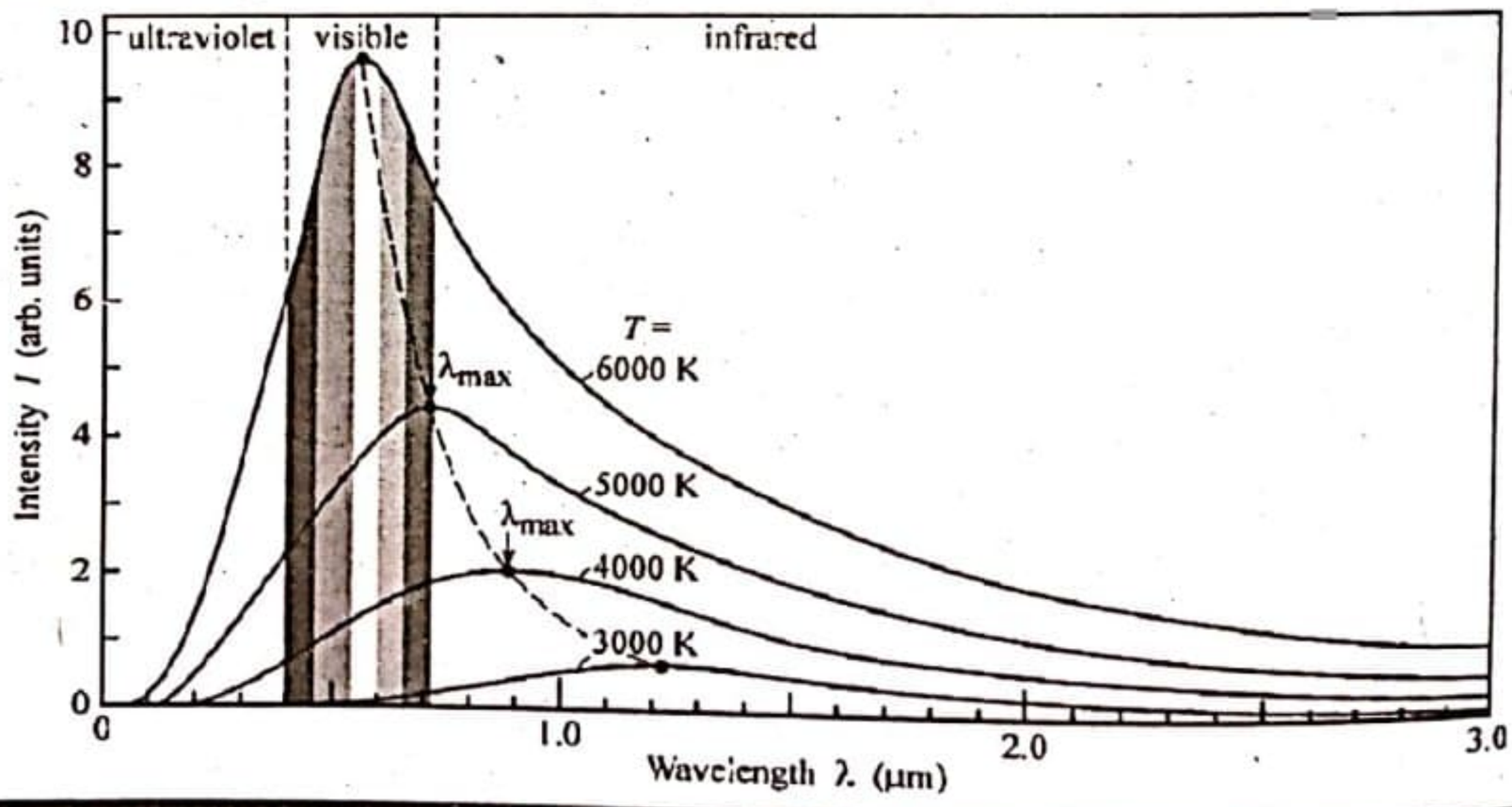
- Shape of black body radiation curve is same and independent of material of the body.
- Classical attempts for explanation of black body radiations are given below.

✦ **Wein's** Displacement law holds good for **shorter wavelength.**

✦ **Rayleigh** Jeans law holds good at **longer wavelength.**

✦ Plank's quantum theory explains the black body radiations that absorption and emission of radiation takes place in the form of packets of energy called quanta i.e. E = hf. It holds good at all **wavelengths.**

✦ Max Plank receive noble prize in 1918 in physics for discovery of energy quanta.



THE PHOTONS

- Einstein presented the idea of light energy consisting of packets of **electromagnetic** energy.
- Max plank explained the emission and absorption by the atoms from a black surface is in the form of indivisible packets called **quanta.**
- Max plank put discontinuous **(granular)** nature of light.
- The beam of light with wavelength λ consists of stream of photons traveling at speed c and carrier energy hf.
- As $E = mc^2$ and $E = hf$

  then $mc^2 = hf$

  or $mcc = hf$

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$$mc = \frac{hf}{c}$$

As $mc = p$ and $f = \frac{c}{\lambda}$ P = momentum

then $p = \frac{h}{\lambda}$

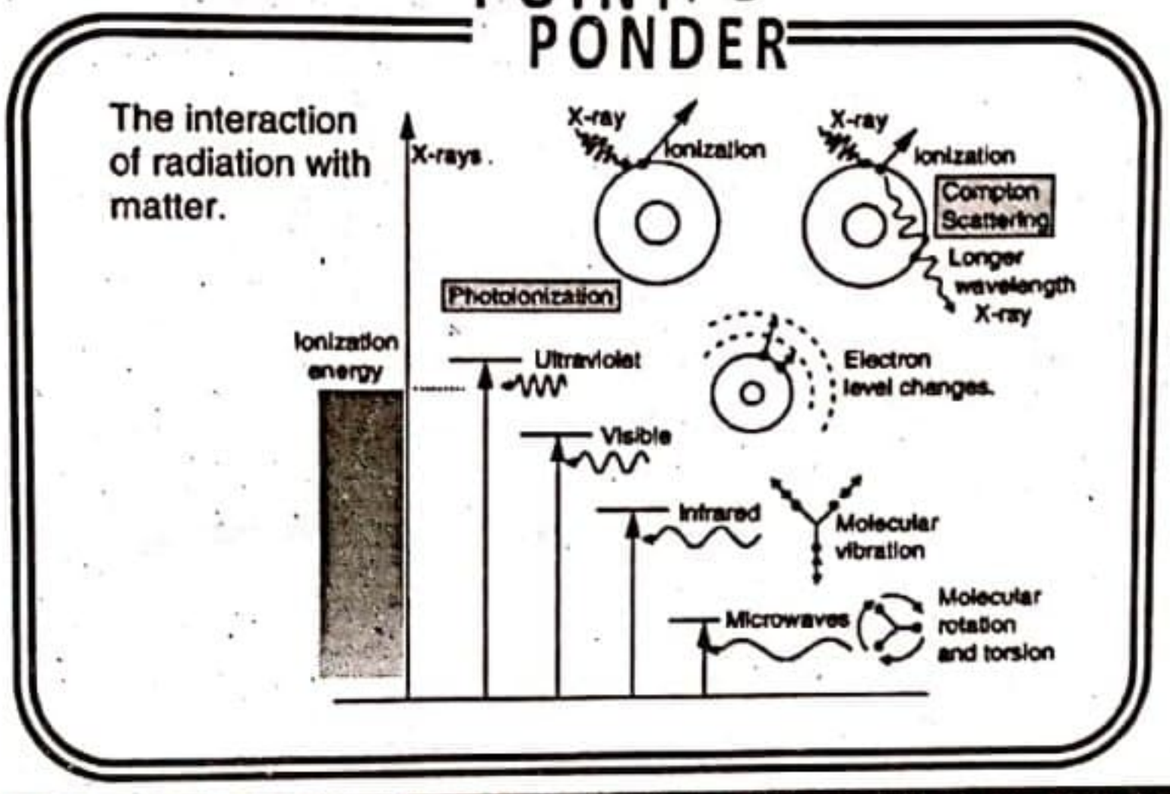
- Emission or absorption of energy is applied to any **oscillating system.**

INTERACTION OF ELECTROMAGNETIC RADIATION WITH MATTER

It is of three types depending upon the energy of photon.

- Photo electric effect — **hf<0.1MeV**
- Compton effect — **0.1MeV<hf<1MeV**
- Pair production — **hf>1MeV**

POINT TO PONDER



PHOTOELECTRIC EFFECT AND PHOTON THEORY OF LIGHT

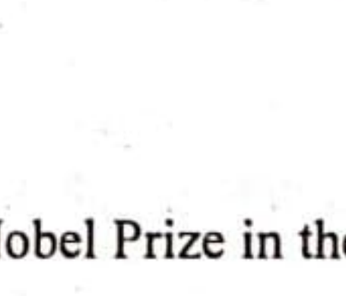
- When light is incident on the surface of a metal electrons are emitted from it. This phenomenon is known as "Photoelectric effect."
- The photoelectric effect supports the quantum nature of light.
- Emitted electrons are known as photoelectrons.
- This effect is based on the principle of energy conservation.
- Photoelectric effect was first explained by Einstein for which he was awarded Nobel Prize in the year 1921.

Study of Photoelectric Effect: **The emission of electrons from metallic surface, when light of specific short wavelength is incident on it is called "Photoelectric effect".**

Hallwach applied some potential difference across two Zn plates in a quartz vacuum tube and studied the flow of current. When ultraviolet light is incident on cathode current flows in the circuit which vanishes when no light falls. When light falls on anode the current in the circuit is negligible.

Effect of Intensity of Incident Light on Photoelectric Current: When the intensity of light of frequency more than the threshold frequency is increased the number of photoelectrons increase i.e., the photoelectric current also increase.

Photoelectric current (i), $i \propto I$ where I = Intensity of light



Effect of Potential on Photoelectric Current

- On increasing the potential current first increases and at a fixed potential reaches a maximum value known as saturation current.

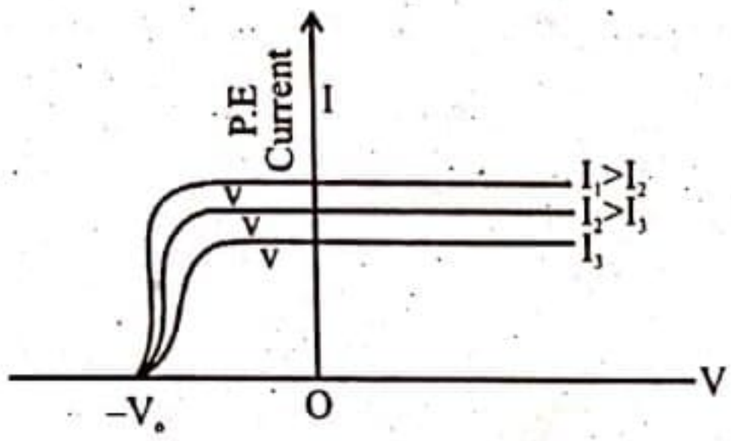
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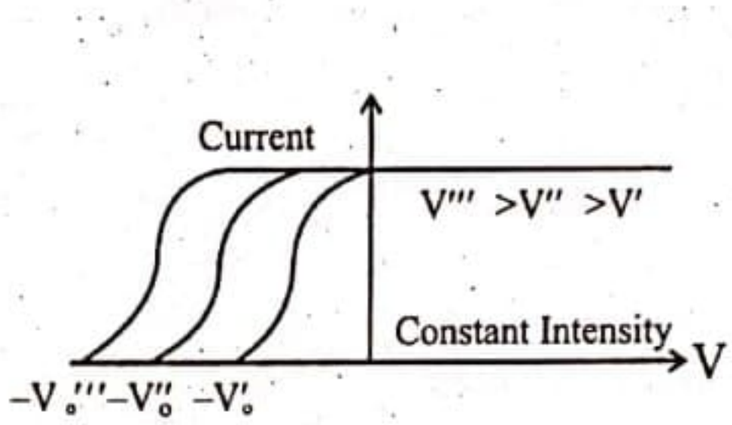
- At a fixed negative potential the value of photoelectric current is zero. This negative potential is called stopping potential.
- The stopping potential is proportional to the maximum kinetic energy of photoelectrons.
- The stopping potential depends on the frequency of the incident light.
- The stopping potential does not depend on the intensity of the Incident light.

Effect of Frequency of Incident Light on Photoelectric Current

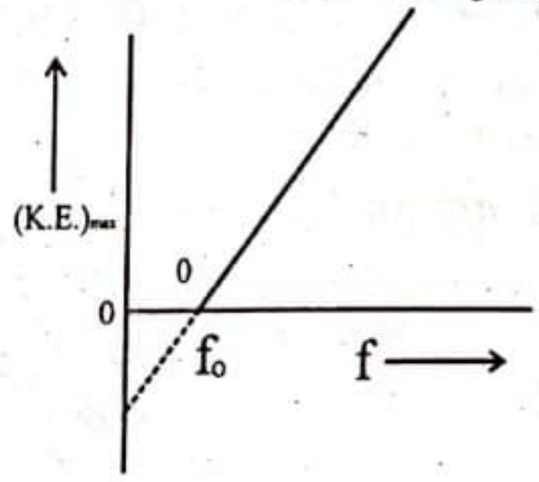
A simple linear relation exists between stopping potential (maximum energy of emitted electron) and frequency of incident photon.

$hf = eV + \phi_o$ or $hf = K.E + \phi_o$ or $\phi_o = hf - K.E_{max}$





Slope of straight line



Laws of Photoelectric Effect

- The rate of emission of photoelectrons from a metallic surface is proportional to the intensity of incident light.
- If the frequency of incident light is less than a specific minimum (whatever the intensity of light) electrons will not be ejected from the surface.
  This minimum (threshold) frequency is different for different metals.
  The photo energy corresponding to threshold frequency is known as work function of metal.

$$\phi_o = hf_o = \frac{hc}{\lambda_o}$$

- The maximum K.E. of emitted photoelectrons is proportional (linearly related) to the frequency of incident light but does not depend on the intensity of incident light.
- The time interval of incidence of light on the metallic surface and electron emission is negligible (less than 10^{-8}s). i..e, the process of electron ejection is instantaneous.

Parameters of Photoelectric Effect

- **Work function (ϕ_o):** The minimum energy required to eject an electron from the metal surface is known as its work function. $\phi_o = hf_o$

  (a) It depends upon:
  - ✦ The impurities present on the surface of the metal
  - ✦ The nature of metal

  (b) Its unit are eV, joule and erg.

  (c) It is a property of material and not of emitted electron.
- **Photo sensitive material:** Those elements that eject photons when high frequency light is incident on the material are called photo sensitive material.
- **Saturated photocurrent:** The maximum value of photocurrent is called saturated current.
- Due to stopping potential the work done by electrons is equal to the maximum kinetic energy of electrons. $eV_o = \frac{1}{2}mv_{max}^2$

Einstein's Explanation of Photoelectric Effect: Light has dual (wave and particle) nature. In interaction of light with matter light acts as particle. According to quantum theory the exchange or propagation of light is in the form of small energy packets called photons.

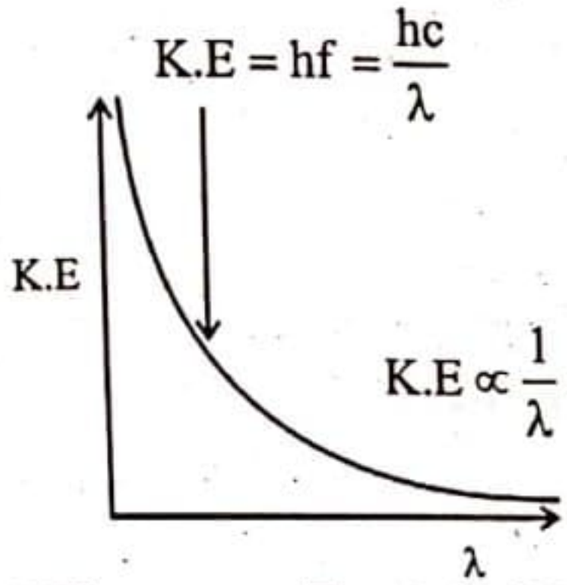
$$E = hf = \frac{hc}{\lambda}$$

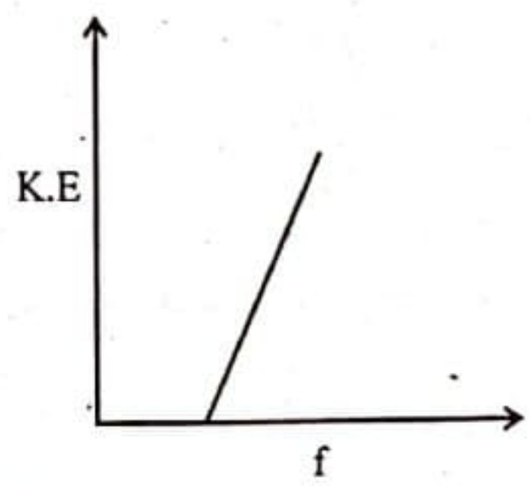
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Einstein's Photoelectric Equation:

$$K.E_{max} = hf - \phi_o = hf - hf_o = h(f - f_o) \quad , \quad \frac{1}{2}mv^2_{max} = hf - \phi_o$$

Important Graphs:





Failure of Classical Theory to Explain Photoelectric Effect:

The wave theory of light completely failed to explain the experimentally established facts about photoelectric effect.

- The fact that maximum kinetic energy of photoelectrons does not depend on intensity of incident radiation.
- The existence of a threshold frequency or wavelength.

A weak beam of radiations having frequency more than threshold frequency can eject a photo electron while an intense beam of frequency lesser than threshold cannot eject a photo electron.

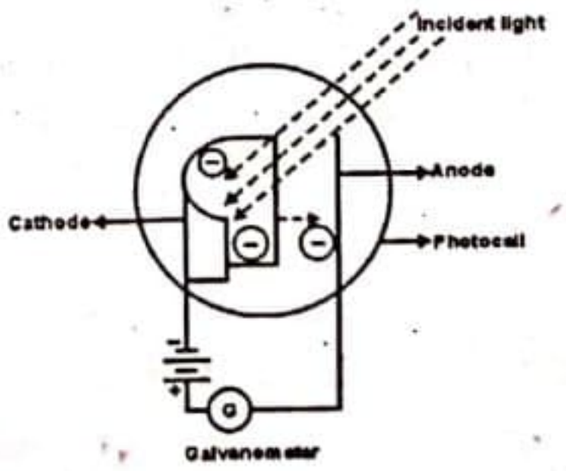
Phenomenon	Can be explained in terms of waves.	Can be explained in terms of particles.
Reflection	✓	✓
Refraction	✓	✓
Interference	✓	⊗
Diffraction	✓	⊗
Polarization	✓	⊗
Photoelectric effect	⊗	✓

PHOTO CELL

- A photocell is based on **photoelectric effect.**
- A simple photocell consists of a glass bulb with a thin **anode rod** and a **cathode** of an appropriate metal surface.
- Sodium or potassium cathode surface emits electrons for visible light.
- Cesium coated oxidized silver emits electrons for infrared light.
- Some surface selenium or silicon emits electrons for ultraviolet rays, X-rays and γ-rays.

Applications of photocells

- ✦ Security system
- ✦ Counting systems
- ✦ Automatic door systems
- ✦ Automatic street lighting
- ✦ Exposure meter for photography
- ✦ Sound tracks of movies
- ✦ Solar panels in watches and other appliances



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COMPTON EFFECT

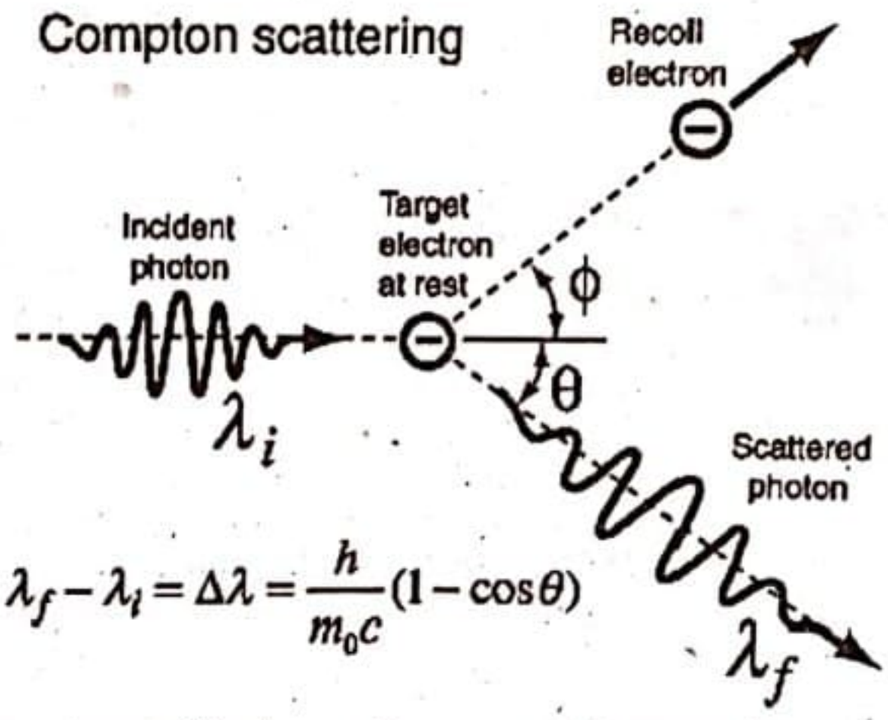
When a photon hits with an electron, it scatters with frequency less than that of incident photon; It is known as **compton effect.**

- Usually X-ray photons are used because of high energy **(≥ 17.5 KeV).**
- Change (increase) in wavelength is called **Compton shift.**

$$\Delta\lambda = \lambda_f - \lambda_i$$

$$\Delta\lambda = \frac{h}{m_o c}(1-\cos\theta)$$

- $\Delta\lambda = \frac{h}{m_o c} = 2.43 \times 10^{-12}$ m is called **Compton wavelength.**
- $\Delta\lambda = 0$ when $\theta = 0°$.
- $\Delta\lambda = \frac{h}{m_o c}$ when $\theta = 90°$.
- $\Delta\lambda = \frac{2h}{m_o c}$ when $\theta = 180°$.

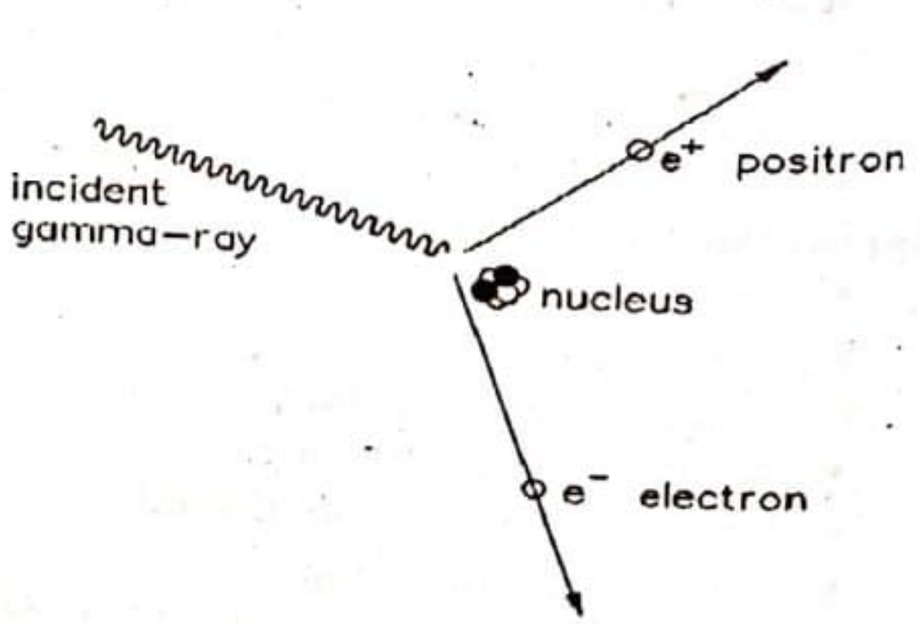


- Photoelectric effect and Compton effect are strong evidences that e.m waves behave as **particle (photon).**
- Compton effect proves **photon** theory of light.

PAIR PRODUCTION

Decomposition of photon into electron, positron pair is called pair production.

- Pair production can takes place only if photon energy is greater than **1.02 MeV.**
- Energy equation for pair production is given as;
- $hf = 2m_oc^2 + K.E_{e^-} + K.E_{e^+}$
- Rest mass energy of electron or positron is $\mathbf{m_oc^2}$ **(= 0.51 MeV).**
- Condition for pair production is that $hf > 2m_oc^2$
- Pair production can not take place in **vacuum**
- The interaction usually takes place in the electric field in the vicinity of a heavy nucleus so that there is a particle to take up recoil energy and momentum is conserved.
- Pair production is **materialization of energy**

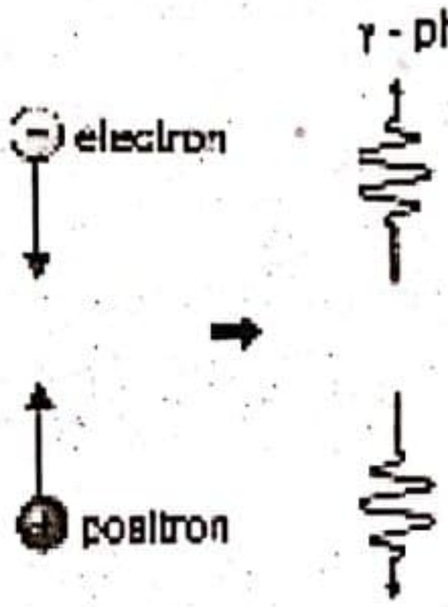


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ANNIHILATION OF MATTER

Reverse process of pair production is called **annihilation of matter.**

- It involves conversion of mass into energy.
- Two photons are produced by the annihilation of electron and positron
- Two photons produced move in opposite direction to obey the law of **conservation of momentum.**
- Each photon has energy of **0.51MeV** equivalent to rest mass energy of electron.



ANTIMATTER

- **P.A.M Dirac** theoretically predicted antimatter in 1928.
- Anderson discovered positron during study of spectrum of cosmic rays in 1932.
- Every antiparticle has same mass, same spin but opposite magnetic moment and charge to its respective particle

PARTICLE	ANTIPARTICLE
Electron	Positron
Proton	Antiproton
Neutron	Antineutron
Neutrino	Antineutrino
Earth	Black hole

De-BROGLIE'S HYPOTHESIS (Wave particle duality)

All the moving particles behave as waves called matter waves or particle waves. The wave length associated with moving particles is given by

$$\lambda = \frac{h}{mv}$$

mv = momentum of particles

$$\lambda = \frac{h}{p}$$

$$\lambda \propto \frac{1}{m}$$

$$\lambda \propto \frac{1}{v}$$

An object of large mass and ordinary speed has such a small wavelength that its wave effects such as interference and diffraction are negligible.

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DAVISSON AND GERMER EXPERIMENT

- **Germer** and **Davisson** using low energy electron beam provided experimental confirmation of **de-Broglie's hypothesis**. They showed that electrons are diffracted from metal crystals in exactly the dame manner as X – rays or any other wave.
- The electron beam of energy Ve is made incident on a nickel crystal. The beam diffracted from crystal surface. The wavelength associated with the moving electrons is given as:

$$\lambda = \frac{h}{mv}$$

$$mv = \sqrt{2mVe}$$

$$\lambda = \frac{h}{\sqrt{2mVe}}$$ where V is accelerating potential

V = 54 V

$$\lambda = 1.66x10^{-10}\, m$$

- This beam of electrons diffracted from crystal surface was obtained for a glancing angle of 65°.

According to Bragg's equation $2d\sin\theta = m\lambda$

For 1st order diffracting m = 1

For nickel $d = 0.91 \times 10^{-10}$m

Which gives $\lambda = 1.65\times10^{-10}\, m$

- Prince Louis Victor de Broglie received the 1929 noble prize in physics Clinton Joseph Davisson and George Paget Thomson shared the Nobel Prize in 1937 for their experimental confirmation of the wave nature of particles.
- Electron microscope is a practical application of wave particles duality.

HEISENBERG'S UNCERTAINTY PRINCIPLE

It states that following pairs of quantities can't be measured with perfect accuracy at same time.

- Linear momentum and position
- Energy and time

Such quantities are called conjugate quantities.

Mathematically,

$$\Delta p \simeq \frac{h}{\lambda}$$

$$\Delta x \simeq \lambda$$

$$\Delta p \,.\, \Delta x = h$$

$$\Delta E \,.\, \Delta t = h$$

- To increase accuracy in measuring position, we should use short wavelength.
- To increase accuracy in measuring momentum, we should use long wavelength.

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Important Considerations

- A ball falling freely appears to fall straight to **stationary observer** and falling along curved path to moving observer. It is due to relative motion.
- If $v = 0.999C$ then $m = 22.4\ m_o$
- Millikan determined the values of 'e' and 'h'.
- Human body emits e.m waves in infrared region at only 310K.
- If $v \geq 2.6 \times 10^8$ m/s , then $l = l_o / 2$ & $m = 2\ m_o$

ELECTROMAGNETIC SPECTRUM

S.#	Name	Wavelength Range (metre)	Frequency Range (hertz)	How Produced
1.	Gamma rays	6×10^{-13}–1×10^{-10}	5×10^{20}–3×10^{19}	Nuclei of atoms
2.	X-rays	1×10^{-10}–3×10^{-8}	3×10^{19}–1×10^{16}	Bombardment of high Z target by electrons
3.	Ultraviolet rays	3×10^{-8}–4×10^{-7}	1×10^{16}–8×10^{14}	Excitation of atoms and vacuum spark
4.	Visible light	4×10^{-7}–8×10^{-7}	8×10^{14}–4×10^{14}	Excitation of atoms, spark and arc flame
5.	Infrared rays	8×10^{-7}–3×10^{-5}	4×10^{14}–3×10^{13}	Excitation of atoms and molecules
6.	Heat radiation	1×10^{-5}–1×10^{-1}	3×10^{13}–3×10^{9}	Heating
7.	Microwaves	1×10^{-3}–3×10^{-1}	3×10^{11}–1×10^{9}	Oscillating currents in special vacuum tubes
8.	Ultra high radio frequencies	1×10^{-1}–1	3×10^{9}–3×10^{8}	Oscillating circuits
9.	Very high radio frequencies	1 – 10	3×10^{8}–3×10^{7}	Oscillating circuits
10.	Radio frequencies	$10 - 10^4$	3×10^{7}–3×10^{4}	Oscillating circuits
11.	Power frequencies	5×10^{6}–6×10^{4}	60 – 50	Weak radiations from A.C. circuits

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20 CHAPTER ATOMIC SPECTRA

SPECTRUM

Spectrum means set of frequencies absorbed or emitted by a substance.

Types

(i) **Emission Spectrum:** set of frequencies emitted by atoms of a substance.

(ii) **Absorption Spectrum:** set of frequencies absorbed by atoms of a substance.

- Absorption spectrum is caused by up **transition** of atomic electrons.
- Each element has characteristic emission spectra in its vapour state.
- Emission spectra fall into following three categories: -

(i) **Continuous Spectra:** It is emitted from condensed matter (solid or liquid). A **black body** spectrum is **continuous spectra**.

(ii) **Line Spectra:** It is emitted by a gas or vapour state of element.

(iii) **Band Spectra:** Molecular spectra is **band spectra**

SPECTRUM OF HYDROGEN

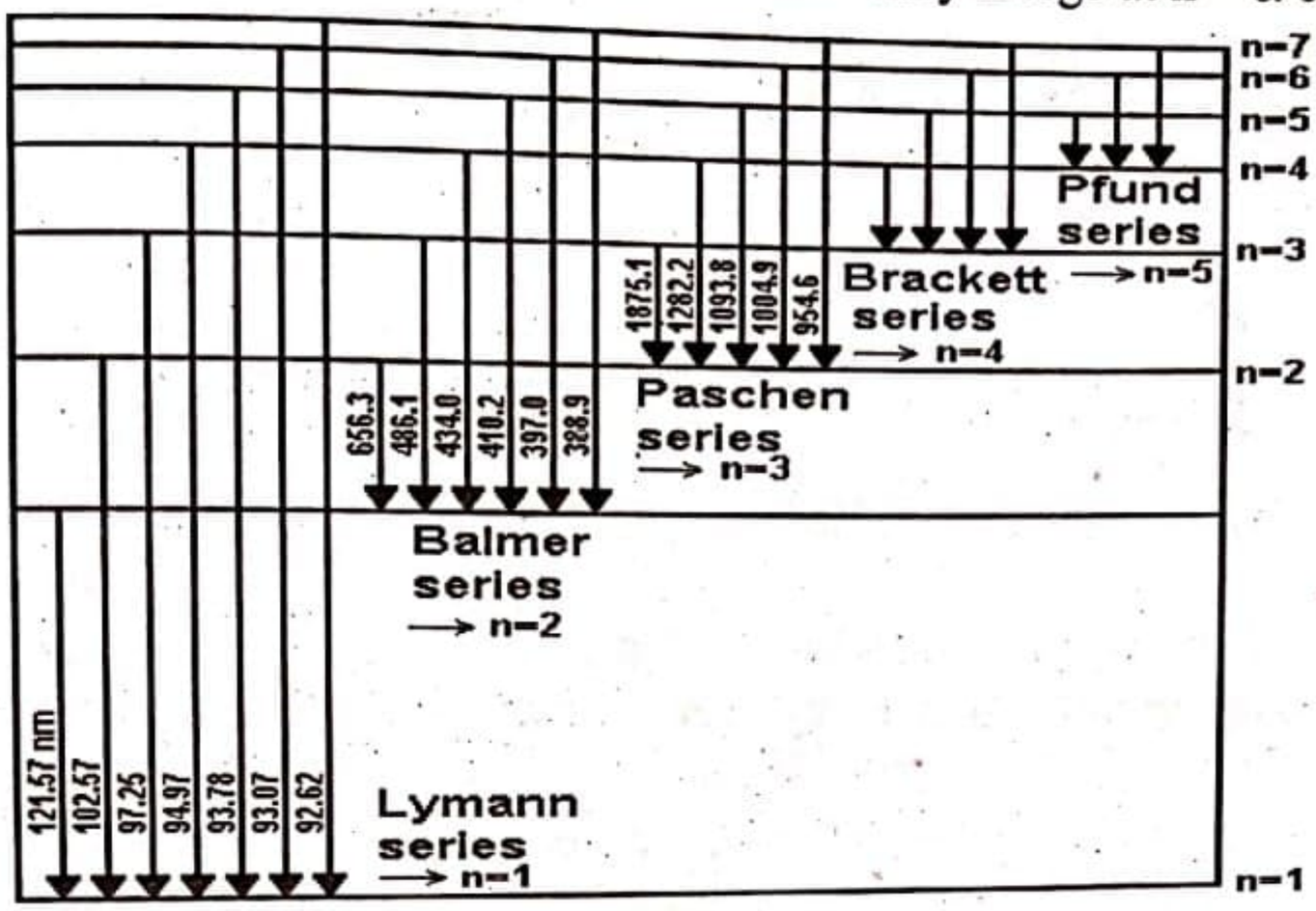
Emission spectrum of H-atom consists of five series or 5 sets of spectral lines.

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \text{ As } n > p$$

Series	Relations	Region	Longest Wavelength	Shortest Wavelength
LYMAN SERIES	$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right)$ $n = 2,3,4.....\infty$	U–V	Put n=2 $\lambda = \left(\frac{4}{3R}\right) = 1216Å$	Put $n = \infty$ $\lambda = \frac{1}{R} = 912Å$
BALMER SERIES	$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$ $n = 3,4,5....\infty$	Visible	Put n=3 $\lambda = \frac{36}{5R} = 6563Å$	Put $n = \infty$ $\lambda = \frac{4}{R} = 3648Å$
PASCHEN SERIES	$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right)$ $n = 4,5,6....\infty$	Infrared	Put n = 4 $\lambda = \frac{144}{7R} = 18761.1Å$	Put $n = \infty$ $\lambda = \frac{9}{R} = 8208Å$
BRACKET SERIES	$\frac{1}{\lambda} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right)$ $n = 5,6,7....\infty$	Infrared	Put n = 5 $\lambda = \frac{400}{9R} = 40533.3\,Å$	Put $n = \infty$ $\lambda = \frac{16}{R} = 14592Å$
PFUND SERIES	$\frac{1}{\lambda} = R\left(\frac{1}{5^2} - \frac{1}{n^2}\right)$ $n = 6,7,8....\infty$	Infrared	Put n = 6 $\lambda = \frac{900}{11R} = 74618.18Å$	Put $n = \infty$ $\lambda = \frac{25}{R} = 22800\,Å$

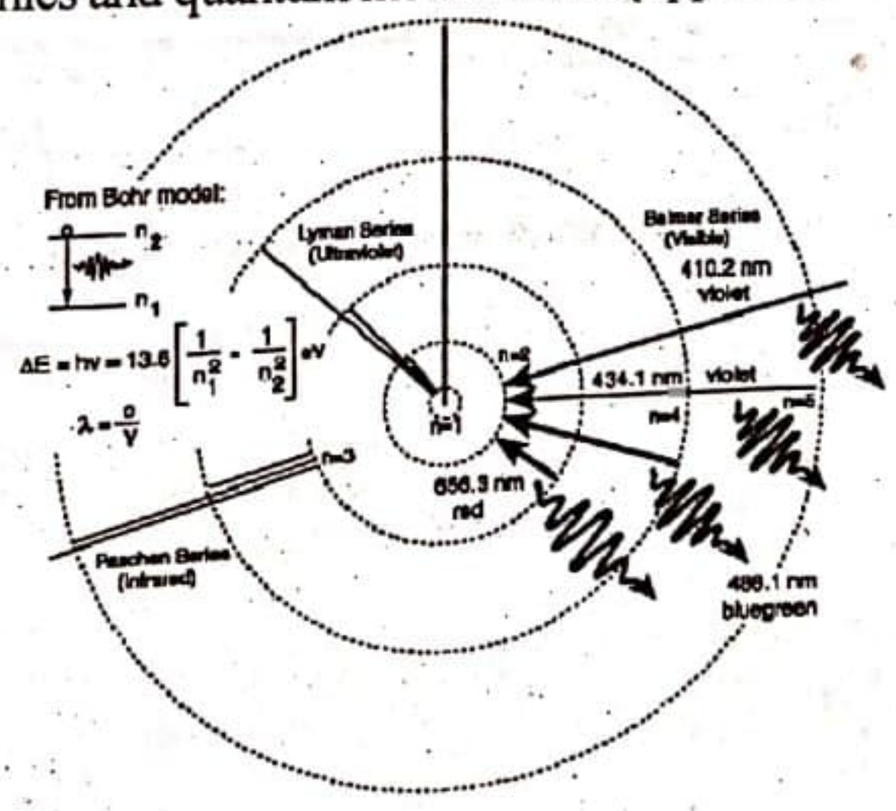
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- All one-electron atoms have atomic spectra like hydrogen atom.
- Spectral lines get closer with increase in value of n until they merge at n = α called series limit.



BOHR'S MODEL

- Bohr, in 1913, proposed his atomic model, to remove **objections** against Rutherford atomic model.
- Bohr's atomic model is a mixture of classical and modern physics.
- Both laws of classical mechanics and quantum mechanics are applicable to atomic system.



Main Points of Bohr's Atomic Model

(i) An electron can revolves only in those orbits in which their angular momentum is **integral multiple of** $\frac{h}{2\pi}$.

$$mv_n r_n = \frac{nh}{2\pi}$$

(ii) As long as electron remains in an allowed orbit, its energy remains constant, in spite of fact that continuously it undergoes angular acceleration.

(iii) Emission or absorption of energy from atom takes place only when its electron undergoes down or up transition between two allowed orbits.

$$\Delta E = E_n - E_p$$
$$hf = E_n - E_p$$

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- Bohr's atomic model produced good results for H-atom and for one- electron atom.
- It can't explain **fine structure** and **hyperfine structure of spectrum**.

Bohr's Calculations

- **Radius** of nth orbit of the atom is given as;

$$r_n = \frac{n^2h^2}{4\pi^2 me^2k}$$

$$r_n = r_o\, n^2$$

Where $$r_o = \frac{h^2}{4\pi^2 m\, e^2k}$$

If n=1 then r_1=0.53 A°(Bohr's Radius)

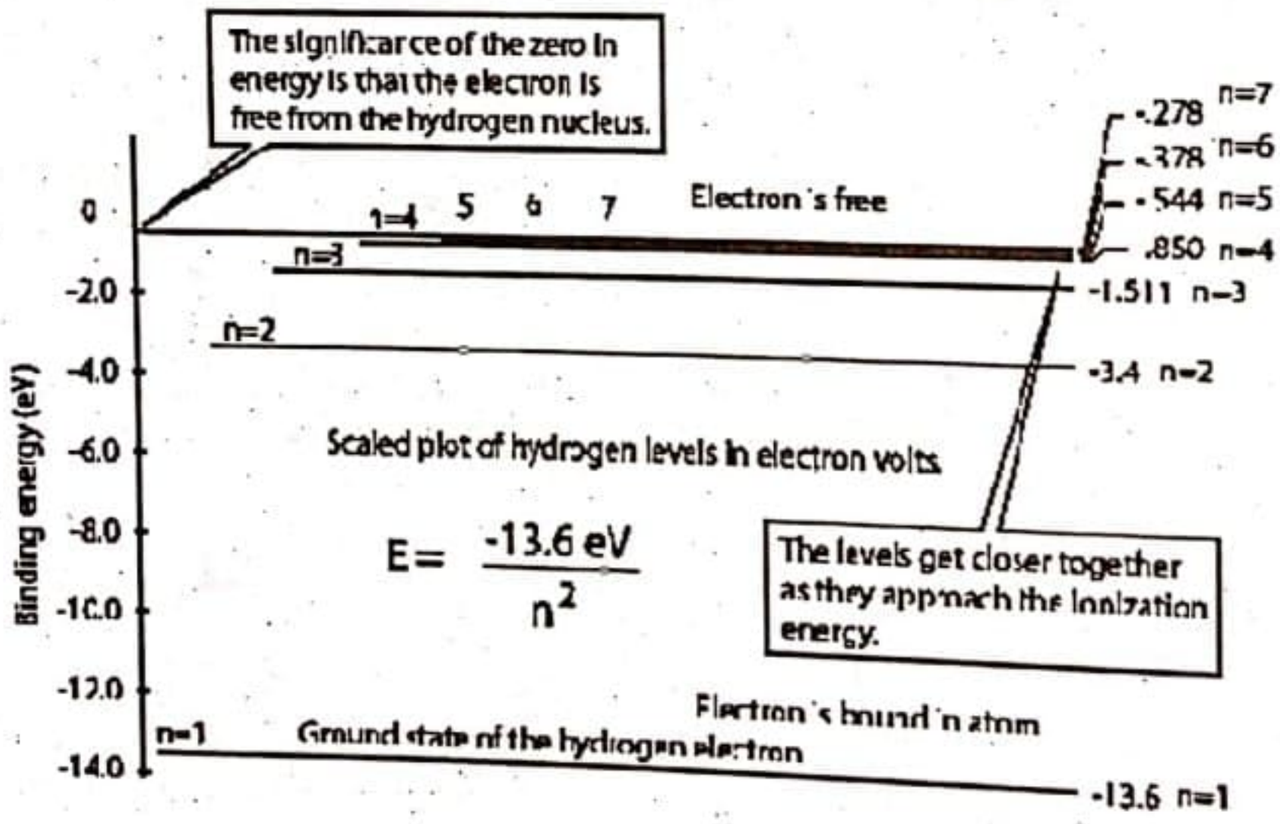
Similarly,

$r_2 = 4r_1$ and $r_3 = 9\, r_1$ and so on.

It shows that radii are **quantized** and they occur in the following ratio:

$r_1:r_2:r_3$:------ = 1:4:9 -----

- The basic structure of the hydrogen energy levels can be calculated from the Schrodinger equation. The energy levels agree with the earlier Bohr model, and agree with experiment within a small fraction of an electron volt.



- **Energy** of electron in an orbit is the sum of K.E and electrical P.E.

$$E_n = KE + PE$$

$$K.E = \frac{ke^2}{2r_n}$$

$$P.E = \frac{-ke^2}{r_n}$$

$$E_n = \frac{-ke^2}{2r_n}$$

- Energy of electron in nth orbit is given as;

$$E_n = \frac{E_o}{n^2}$$

Where $$E_o = \frac{2\pi^2e^4mk^2}{h^2} = 13.6\ eV$$

E_1 = -13.6eV for n = 1

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$E_2 = -3.4$ eV for $n = 2$

$E_3 = -1.51$ eV and so on. for $n = 3$

- Graph of equation $E_n = -E_o/n^2$ is called **energy level diagram.**
- Formula for the wavelength of nth orbit is given as;

$$\frac{1}{\lambda_n} = R_H\left(\frac{1}{p^2} - \frac{1}{n^2}\right)$$

Where $n > p$

R_H = Rydberg's constant $= 1.0974 \times 10^7\ m^{-1}$.

De-BROGLIE'S INTERPRETATION OF BOHR'S ORBIT

- Third postulate of Bohr's atomic model is deduced from Plank's thesis.
- Second postulate is justified by de-Broglie
- ✦ Electrons move in orbits in the shape of standing waves
- ✦ Orbital velocity of electron in innermost orbit is **2.19×10^6 m/sec,**

ENERGIES & POTENTIALS

Excitation Potential: The potential required to raise the electron from ground state to higher state. e.g. for hydrogen,

1^{st} excitation potential = 10.2 eV

2^{nd} excitation potential= 12.1eV

Ionization Potential: The potential required for ionization of atom e.g. for hydrogen, **13.6 V** is ionization potential.

Note:

(i) There is a large no. of excitation potentials and only limited no. of **ionization potentials**.

(ii) Each next ionization potential is greater than its preceding one.

Excitation Energy: The energy required to raise the atom from ground state to higher state.

Ionization Energy: The energy required to remove electron from atom

Three ways for excitation or ionization of atom

(i) Photo ionization or excitation: photon of specified energy is incident.

(ii) Bombardment ionization or excitation: charged particle e.g. electron is incident on atom.

(iii) Thermal ionization or excitation: heat is provided.

X-RAYS

Characteristic X-Rays

- When core electron is ionized from heavy atom, then electron jumps down to occupy its place. This process is called **inner shell transition.**
- Inner shell transition is the origin of **characteristics X-rays.**
- X-rays are e.m waves having wavelength 1A° to 0.5A°.
- Characteristic X-rays are emitted due to down **transition** of electron.
- A characteristic X-rays appear as discrete lines on **continuous spectrum.**
- The X-rays produced due to transitions to K- shell are called primary X-rays. e.g. K_α, K_β, K_γ etc.

$$hf_{k\alpha} = E_L - E_K$$

$$hf_{k\beta} = E_M - E_K$$

Such X-ray photons are emitted due to transition from L, M, N orbits to K-shell respectively.

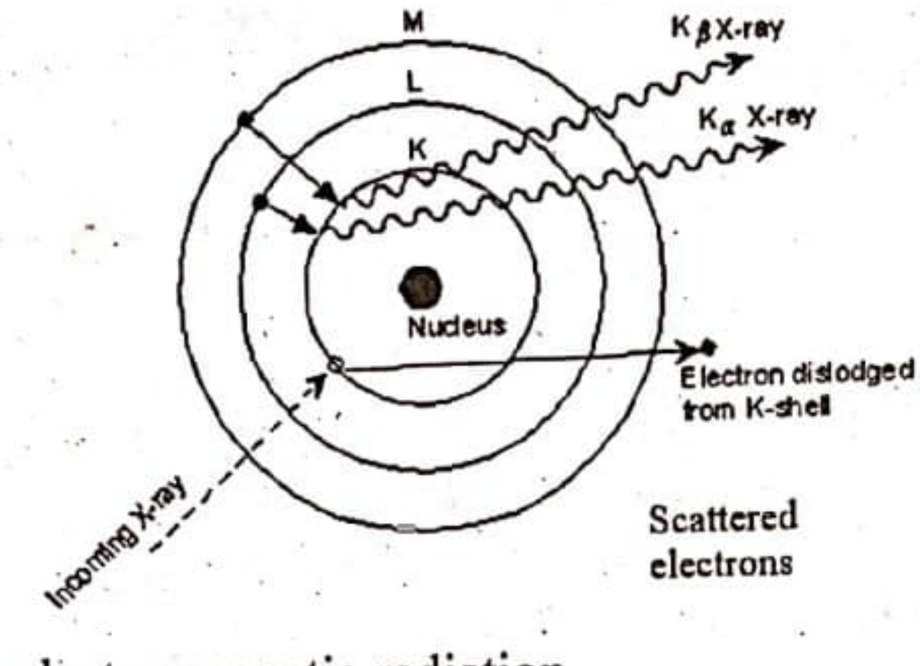
Ejected Electrons

- A German physicist Roentgen discovered X-rays in December 1895.

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Continuous X-Rays Spectrum

- The continuous spectrum is due to an effect of **bremsstrahlung** or **breaking radiation.**



- Accelerating charge emits electromagnetic radiation.
- Due to deceleration of electrons in the target, X-ray radiation is emitted called continuous background radiation or breaking radiation.

$$Ve = hf_{max}$$

- Continuous background radiations are of relatively smaller wavelength.

X-Ray Production

- Gas filled X-ray has three drawbacks:

(i) Quality can't be controlled.

(ii) Pressure decreases, so does X-rays intensity.

(iii) 98% of incident electron energy is wasted as heat and only 2% is converted in to X-rays.

- Modern X-ray unit consists of following main parts: -

Source: It is step up transformer that produces high voltage.

Target: It is a piece of heavy metal with large atomic no. like cadmium.

Filament: It is an electron source. It consists of concave shaped metal heated by **D.C operated heater** (100 mA to 500 mA).

Copper Rod: It conducts out heat.

Cooling Fins: It is a cooling spring in which cooling water or oil circulates.

Biological Shield: It is lead case covering the whole assembly.

Window: It is a transparent window for the escape of X-rays.

- Intensity of X-rays is controlled by heater current (100 mA → 500 mA).
- Quality of X-rays is controlled by source voltage (25 KV → 100KV).

Properties of X-Rays

- X-rays are not affected by **electric** and **magnetic** fields.
- Frequency is greater than **ultraviolet.**
- Straight-line propagation.

X- Rays Exhibits:

- Reflection.
- Refraction.
- Interference.

POINT TO PONDER

The oil of higher specific heat flows in the cooling fines of x-ray production apparatus to sink the large amount of heat produced by head on collision of particles in x-ray generation

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- Diffraction (by NaCl crystal)
- Polarization.

X-Rays Can Performs

- Pass through certain opaque materials.
- Ionization.
- Photoelectric effect.
- Compton effect.
- Blackening of photographic plate.
- Damage to living cell

Uses of X-Rays

(i) Fracture study. (Shadow Photography)
(ii) Medical diagnosis (such as **tuberculosis**).
(iii) Medical treatment (such as cancer).
(iv) Hidden things can be located (such as **weapons** and contraband things).
(v) Research field (such as X-ray diffraction for crystal structure).
(vi) Industrial uses (such as to locate **internal defects**)
(vii) Authenticity of paintings.
(viii) CAT-scanner: CAT stands for computerized axial tomography. The x-ray source produces a thin fan shaped beam that is detected on the opposite side of the subject by an array of several hundred detectors in a line. Tumors, and other anomalies much too small to be seen with older techniques can be detected.
(ix) X-rays cause damage to living tissues.
(x) X-rays are used for destruction of cancer cells
(xi) X-rays can cause cancer
(xii) X-rays can cause changes in the productive system thus damages the organism's offspring.

UNCERTAINITY WITH IN ATOM

We can prove on the basis of Heisenberg equation that electrons cannot exist in nucleus.
i.e.

If electron is in nucleus

then

$$\Delta x = 10^{-14}m$$

so using equation

$$\Delta p \geq \frac{h}{\Delta x}$$

we find

$$\Delta v = 7.3x10^{10}m/sec$$

$$\Delta v > c$$

Which is not possible.
So we, can check the possibility for $\Delta x = 5x10^{-11}m$ (size of atom).
Repeating the same procedure we get

$v = 1.46x10^{7}$ m/sec. Which is possible.

Because $v < c$

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So it shows that electron is **within atom** but not in nucleus. So we can conclude that electrons can only be found in the space in between atom and nucleus called shells.

LASER

Spontaneous and Stimulated Processes

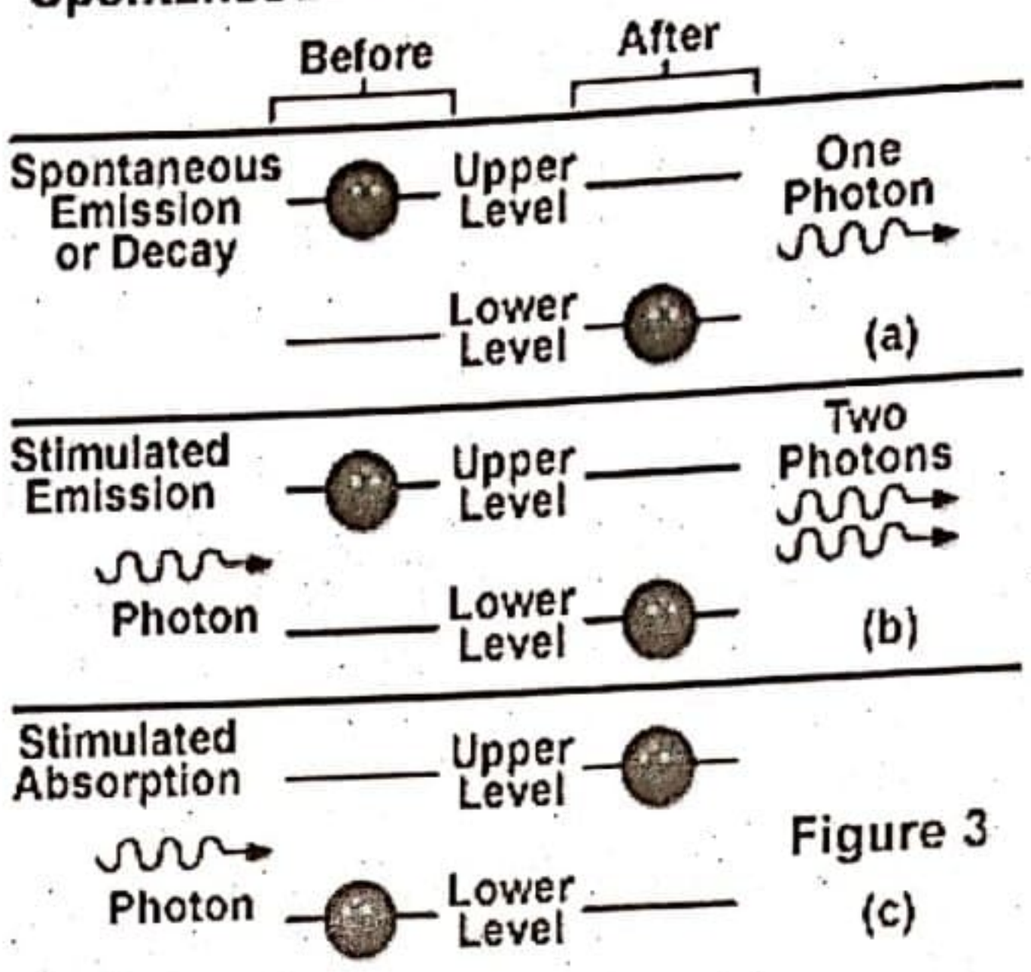


Figure 3

Characteristics of Laser

- Laser stands for **light amplification by stimulated emission of radiation.**
- Einstein developed theory of LASER in 1917.

LASER has following characteristics: -

1- Monochromatic 2- Unidirectional 3- Coherent

4-. Sharply focused 5- Highly polarized

Basic Terms Regarding Laser Production

Metastable States: It is a high energy level in which electron can stay for long time (10^{-3} sec).

Optical Pumping:

It is process of providing energy to initiate and maintain the process.

Population Inversion:

The situation in which number of excited atoms exceeds the number of atoms in ground state.

Resonance:

When stimulated photon passes by excited atoms, it stimulates it to radiate photon of same energy (by going to ground state) by the principle of resonance.

Stimulated Emission:

In stimulated emission the incident photo induces the atom to decay by emitting a photon that travels in the direction of the incident photon.

Coherence:

It means that stimulated photons have same frequency and wavelength.

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POINT TO PONDER

The laser beams actually eject out from a partially mirrored surface so that the reflected photon can further carry out the stimulated emission process

Laser Unit

Important parts of LASER unit are as follows:

(i) Cavity

(ii) Lasing material

(iii) Energy source

Types of Laser

TYPE OF LASER	EXAMPLES
Solid laser	Ruby laser, Semi-conductor laser
Gas laser	He-Ne laser, CO_2 laser
Liquid laser	Methanol + Die laser

Properties of Laser

(i) Monochromatic **(ii)** Coherency **(iii)** Unidirectional

(iv) Reflection **(v)** Refraction **(vi)** Diffraction

(vii) Polarization **(viii)** Affect photographic plate

(ix) May damage (high energy laser) living tissues.

Applications of Laser

(i) Laser as weapon (Laser-guided missiles)

(ii) Laser in industry (Drill tiny holes in steel & diamond)

(iii) Laser in research (Develop hidden finger prints)

(iv) Laser in medical treatment (Surgery of tumors, welding of retina, crush gall stones and kidney stones)

(v) It is potential energy source for inducing fusion reactions.

(vi) Laser in holography (Hologram)

(vii) Holograms are three-dimensional images.

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21 CHAPTER NUCLEAR PHYSICS

J.J. THOMSON'S MODEL OF ATOM

Postulates

(i) Atom is a neutral as a whole, in which negative electrons are embedded on positive nucleus.
(ii) Density of atom is **uniform.**
(iii) There is no empty space in the atom.

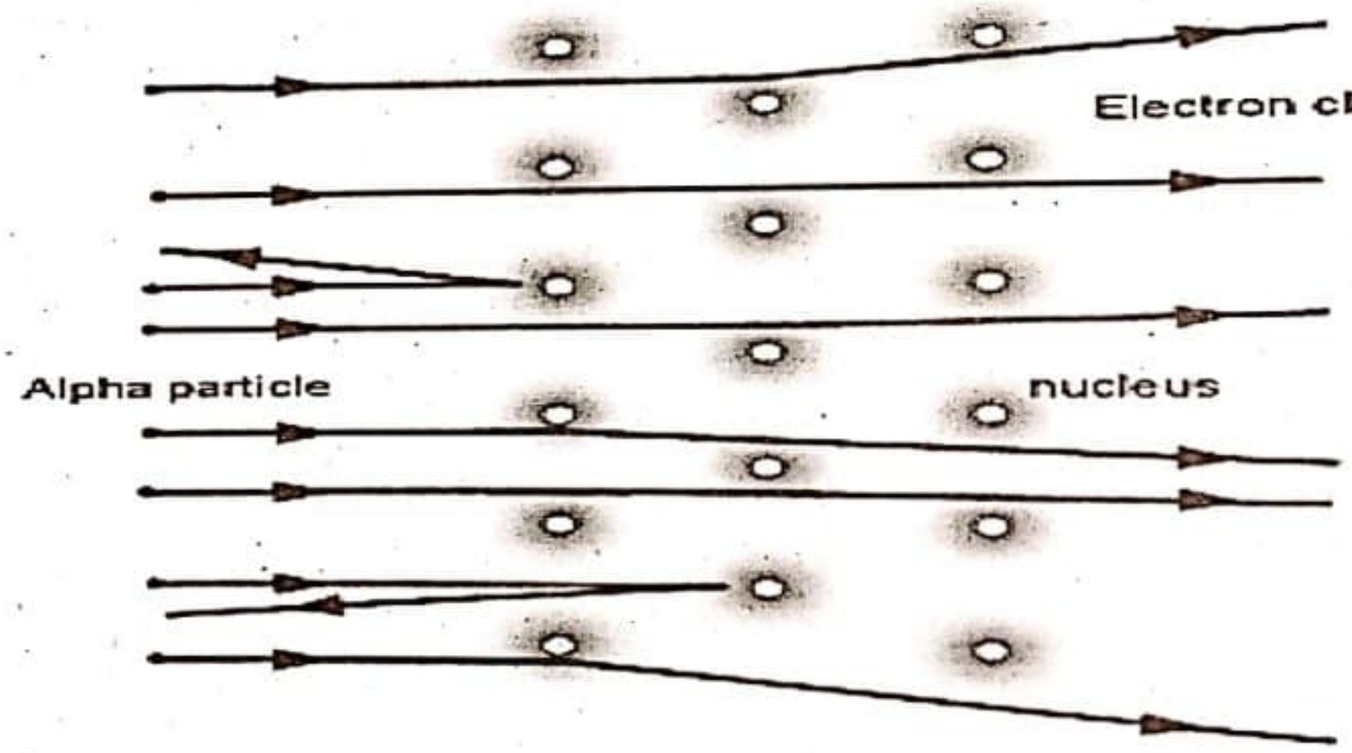
Objections

(iv) There is no static equilibrium between electron and positive charge.
(v) Density of atom is **not uniform.**

RUTHERFORD'S ATOMIC MODEL

Postulates

(i) Most of the part of atom is empty.
(ii) Central part is tiny and positively charged. It is called **nucleus.**
(iii) Electrons are revolving about nucleus in **circular orbits.**
(iv) Almost whole of mass is **concentrated** in nucleus (i.e. atom has non-uniform density).



Objections

(i) The revolving electrons if moving **continuously**, will emit energy **continuously.**
(ii) If energy is emitted continuously, then spectrum should be **continuous** but a line **spectrum** is obtained.
(iii) If energy is emitted continuously, then atomic assembly will collapse

BOHR'S ATOMIC MODEL

Postulates

(i) Electron can revolve only in those orbits in which its angular momentum is integral multiple of $\frac{h}{2\pi}$

$$mvr = \frac{nh}{2\pi}$$

Such orbits are called **allowed orbits** or stationary state or Bohr's orbits.
(ii) As long as an electron remains revolving in its allowed orbit, the energy of electron remains **constant.**

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(iii) When electron jumps down between two allowed orbits, it **radiates** energy in the form of photon of energy as given below.

$$\Delta E = E_2 - E_1 = hf$$

Objections

(i) Electronic orbits are not **circular.**
(ii) Fine structure of atomic spectra could not be explained.
(iii) Effect of nuclear motion on atomic spectra is not made **clear.**

NUCLEUS & ITS COMPOSITION

- Nucleus is a tiny region in which almost all mass of atom is **confined.**
- Rutherford thought that whether nucleus is a lump of mass or it is an **aggregate** of particles.
- Size of atom is $\mathbf{10^{-10}m}$ and that of nucleus is $\mathbf{10^{-14}m}$.
- According to Rutherford's findings, nucleus is composed of neutron and **proton, collectively known as nucleons,** symbolized as:

$$_zX^A$$

Where Z = no. of electrons or protons in neutral atom = charge no.
A = sum of proton and neutron in a nucleus = mass no.

So,

No. of neutron = N = A - Z

- In small atom N=Z, while in heavy atom N>Z.

Discovery of Nucleons

(i) Proton (by Rutherford)

$$_2He^4 + {}_7N^{14} \rightarrow {}_8O^{17} + H^1$$

(ii) Neutron (by Chadwick)

$$_2He^4 + {}_4Be^9 \rightarrow {}_6C^{12} + {}_0n^1$$

- Hydrogen (simple hydrogen) is the only atom whose nucleus contains **no neutron.**
- According to modern research, the number of particle existing in nucleus is 37.
- Mass of nucleus is roughly equal to sum of masses of nucleons.
- Unit of mass at atomic level is a.m.u.

$$1 \text{ a.m.u} = 1.66 \times 10^{-27} \text{ kg}$$

According to the equation $E = mc^2$ 1 a.m.u ≡931 MeV

- Masses of some well-known particles on a.m.u scale are given below;

Particle	Symbol	Mass (in a.m.u)
Electron	$_{-1}e^\circ$	0.00055 a.m.u
Proton	$_1H^1$	1.007276 a.m.u
Neutron	$_0n^1$	1.008665 a.m.u
Deuteron	$_1H^2$	2.014102 a.m.u
Helium nucleus	$_2H^4$	4.002603 a.m.u

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POINT TO PONDER

We can calculate number of neutrons in a nucleus by simply subtracting mass number and atomic number i.e. $_{92}U^{235} \rightarrow 235-92=143$
So this nucleus contains 143 neutrons.

ISOTOPES

"Isotopes are such nuclei of an element having the same atomic number but different mass number."

- Isotopes have same number of protons.
- They have different number of neutrons.
- Isotopes of an element have the same **chemical** but different **physical** properties.

MASS SPECTROGRAPH

Mass spectrograph is an electromagnetic instrument used for the measurement of **masses** of isotopes.

Principle of Mass Spectrograph

$$r \propto \sqrt{m}$$

- Radius of path described by charged ion in mass-spectrometer is given as;

$$r = \sqrt{\frac{2Vm}{B^2e}}$$

Where V = potential difference
e = charge
B = magnetic field

- Mass spectrograph sorts out positive ions
- Centripetal forces of the magnetic field provide the isotopes a suitable radius to bend about.

NUCLEAR FORCES

- Nucleus contains protons that repel each other, may cause the destruction of **nucleus**.
- There are two classical forces, operating in nucleus.

(i) Coulomb's repulsive force;

$$F_e = \frac{K e^2}{r^2}$$

(ii) Newton's attraction force;

$$F_g = \frac{Gm^2}{r^2}$$

- Classical forces are unable to give stability to the nucleus because;
- Due to strong repulsive forces in nucleus, it requires much energy for the entry of another charged particles e.g. proton.

Example: 7.2 MeV energy is required to the addition of 1 proton into a nucleus of 50 **protons**

- Force, which has binding effect on nucleons to give stability of nucleus, is called **strong nuclear force.**

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Properties of Strong Nuclear Force

(i) It does not obey inverse square law.

(ii) It is the strongest force having range equal to nuclear diameter 10^{-14}m.

(iii) It is always attractive force and has binding effect inside the nucleus.

(iv) Strong nuclear force is attractive only within nucleus while a strong force of repulsion is outside the nucleus because of coulomb's **repulsive force.**

MASS DEFECT

Mass defect is the difference between mass of **nucleus** and sum of **masses** of its **nucleons.**

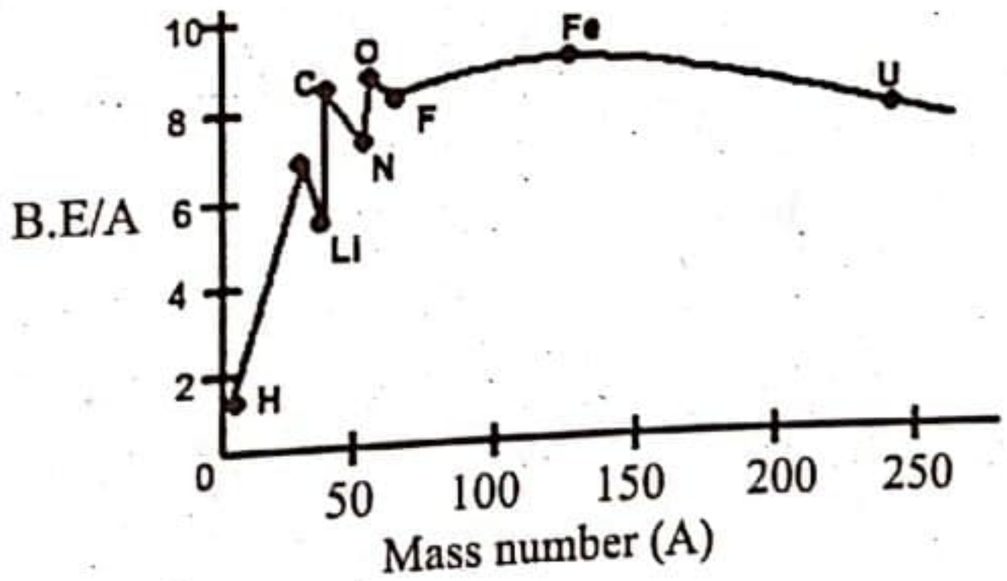
Δm = sum of masses of nucleons – mass of nucleus

e.g. for deuterium ($_1H^2$), $\Delta m = 0.002388$ a.m.u

- Mass defect Δm is converted into energy Δmc^2 called **binding energy**. It is liberated in the form of photon.

$$E = \Delta m \times 931MeV = [(Z\, m_p - N\, m_n) - m] \times 931MeV$$

- After liberation of binding energy ($E = \Delta\, mc^2$), the nucleus becomes stable e.g. B.E for deuterium is **2.24 MeV.**
- When energy equal to binding energy is provided to nucleus, somehow, the nucleus dissociates into nucleons.
- Binding energy can be given as energy required to dissociate nucleus into **nucleons.**
- Graph between mass number (A) and B.E per nucleon is shown below:



- Following conclusions can be drawn from above curve:

(i) Binding energy of a light atom is very large, that is why they are stable (maximum value is at A=56).

(ii) Binding energy per nucleon for heavy atoms is smaller, that is why they are less stable.

(iii) Binding energy (B.E) increases with increasing A. B.E decreases with increase in A if Z > 82.

(iv) The binding energy per nucleon is maximum for iron.

- $\Delta m/A$ is called **packing fraction**

RADIOACTIVITY

- Becquerel discovered **radioactivity.**
- Nuclei having Z > 82 are unstable and they emit α, β and γ rays; the phenomenon is called **radioactivity.**
- Some radioactive elements are Po (Z=84) Rd (Z=88) and U (Z=92) etc.

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α-decay

Charge no. (Z) decreases by 2 and mass no. (A) by 4

$$_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + {}_{Z}He^{4} + Q$$

e.g.

$$_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4} + 4.3\ MeV.$$

β-particle

β-particle is electron or positron coming from nucleus. So it may be classified as;

(i) β^- decay

$$_{z}X^{A} \longrightarrow {}_{z+1}Y^{A} + {}_{-1}e^{\circ} + \upsilon +$$

Only charge no. (Z) **increases by 1.**

Its prototype is decay of neutron itself that changes to p and $_{-1}e^{\circ}$.

$$_{0}^{1}n \longrightarrow {}_{1}^{1}p + {}_{-1}e^{\circ} + \bar{\upsilon}$$

e.g.

$$_{11}Na^{24} \longrightarrow {}_{12}Mg^{24} + {}_{-1}e^{\circ} + \bar{\upsilon}$$

(ii) β^+-decay

$$_{z}X^{A} \longrightarrow {}_{z-1}X^{A} + {}_{+1}e^{\circ} + \bar{\upsilon}$$

Only charge no. (Z) **decreases by 1.**

Its prototype is decay of proton itself that changes to n and $_{-1}e^{\circ}$.

$$_{1}^{1}p \longrightarrow {}_{0}^{1}n + {}_{+1}e^{\circ} + \upsilon$$

e.g.

$$_{9}F^{17} \longrightarrow {}_{8}O^{17} + {}_{+}e^{\circ} + \upsilon$$

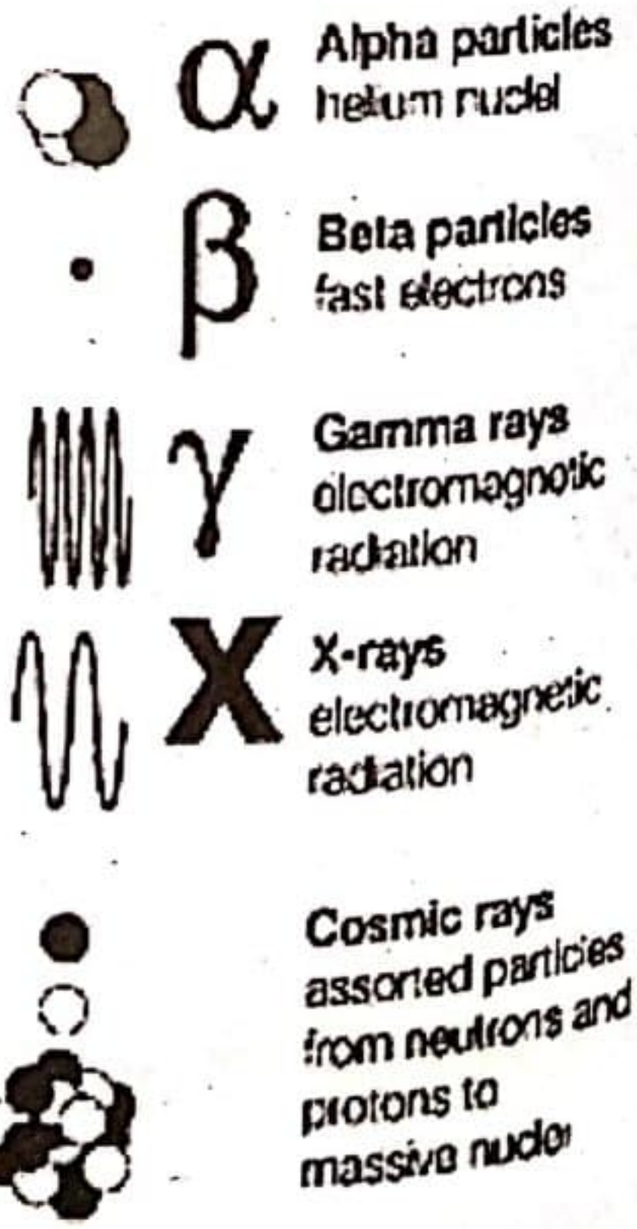
NOTE: Weak interaction only appears in β-decay.

γ-decay

γ-decay is due to de-excitation of nucleus.

e.g. zX^{A*} $zX^{A}+\gamma$, * show **excitation of** atom

$$_{38}{}^{*}Sr^{87} \longrightarrow {}_{38}Sr^{87} + \gamma \text{ - photon}$$



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Type of Radiation	Alpha particle	Beta particle	Gamma ray
Symbol	α or $^4_2\alpha$ or ^4_2He	βor β^-	γ (can look different, depends on the font)
Mass (atomic mass units)	4	1/2000	0
Charge	+2	-1	0
Speed	slow	fast	very fast (speed of light)
Ionizing ability	high	medium	0
Penetrating power	low	medium	high
Stopped by:	paper	aluminium	lead

HALF-LIFE

Half-Life of Elements

- Radioactive decay is a random process so we get idea of **half-life.**
- The half-life $T_{1/2}$ of a radioactive element is that period in which half of the atoms decay.
- Half-life ($T_{1/2}$) depends on element and is not affected by any physical change or chemical change.
- Half-life may be classified as follows:

(i) **Extremely Short Half-Life:** $T_{1/2}$ in micro or nano seconds
(ii) **Moderate Half-Life:** $T_{1/2}$ in minutes.
(iii) **Long Half-Life:** $T_{1/2}$ in years.

- Half- life can be given as: $\mathbf{T_{1/2} = 0.693/\lambda}$

Where λ is called **decay constant** depends upon nature of material. Decay constant of any element is equal to the fraction of the decaying atoms per unit time. The unit of the decay constant is s^{-1}.

- The decay curve shows that radioactive element decay exponentially
- Half-life is used to identify an atom.

Laws of Radioactivity

- $\Delta N/\Delta t \quad \alpha N_o$
- $\Delta N/\Delta t = -\lambda N_o$
- $N_t = e^{-\lambda t} N_o$
- $T_{1/2} \alpha 1/\lambda$
- $\lambda = \frac{\Delta N/\Delta t}{N_o}$ or $\lambda = \frac{\Delta N/N_o}{\Delta t}$
- Mean life $= T = 1/\lambda$

INTERACTION OF RADIATION WITH MATTER

α, β & γ rays are called nuclear radiations.

- Interaction of nuclear radiations with matter depends on three characteristics of nuclear radiations.

(i) Mass of particle
(ii) Charge of particle
(iii) Energy of particle

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(iv) Density of the medium
(v) Ionization potentials of the atoms of the medium

Interaction of α-Rays

- α-particle can do ionization in following two ways.
  (i) Mechanical collision (α- particle directly hits electron)
  (ii) Coulomb's interaction (electrostatic interaction)
- Mode of ionization by Coulomb's interaction (electrostatic attraction) for α-rays dominates over that by direct collision.
- The path of ionization followed by α-rays is straight and continuous because of its high **ionization power and large mass.**
- During ionization, α-particle continuously looses its energy as a result of which its velocity decreases.
- 7.7 MeV α-particle produces $2x10^5$ ion pairs before stopping.
- When α-particle has spent all its energy on ionization, it absorbs two electrons from its surroundings gas and becomes a neutral (He atom).
- Range of α-particle in air is small due to intense ionization.
- 7.7 MeV α-particle has 7 cm range in air at S.T.P, which reduces further in denser medium.
- Range of 7.7 MeV α-particle in aluminum is only 0.04 mm.
- α-particle produces disintegration in nuclei of some atoms if they have high energy.

Interaction of β-Rays

- β-particles are fast electrons or positrons coming from nucleus.
- Range of β-particle is larger than that of α-particle by a factor of 100.
- Ionization of β-particle is smaller than that of α. (100 times less)
- Mass of β-particle is equal to that of an electron.
- Charge of β-particle is equal to $1.6x10^{-19}C$ that may be positive for positron (β^+) and negative for electron (β^-).
- β-particle does ionization due to electrostatic repulsion (in case of β^-) and attraction (in case of β^+).
- Ionization path of β is broken and **zigzag due to its** smaller mass.
- Ionization by head-on-collision is very rare.
- β-particle looses almost all its energy in a single encounter.
- Because of lesser ionization encounters, penetration of β is 100 times larger than that of α-particle of same energy.
- 3 MeV β-particle can pass through 6.5mm aluminum foil.
- β-particle can produce fluorescence.

Interaction of γ-Rays

- γ-rays being photons can't be stopped by matter (lead can be used as a shield because of its high electron density).
- γ-rays have shorter wavelength than X-rays.

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- γ-particles loose their energy by following three ways.

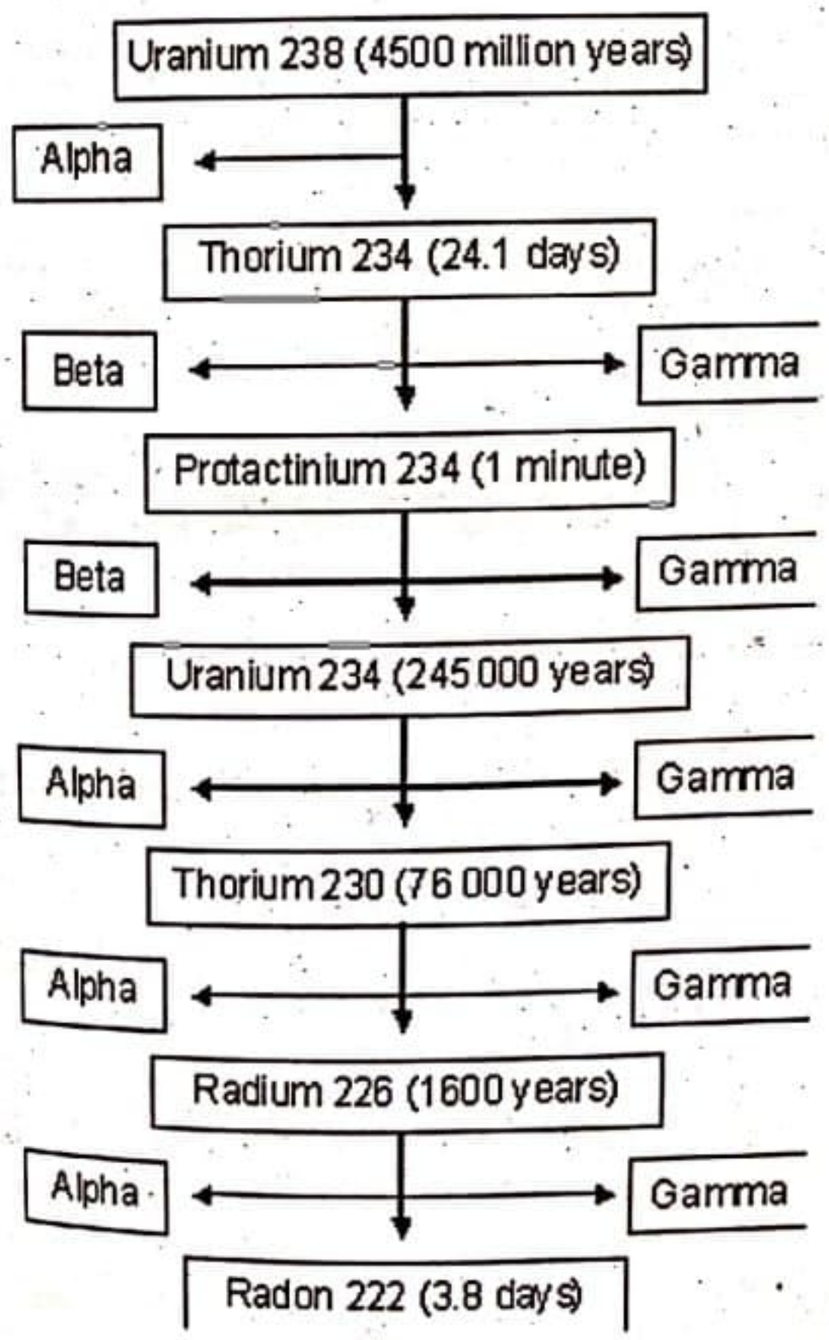
(i) Compton effect

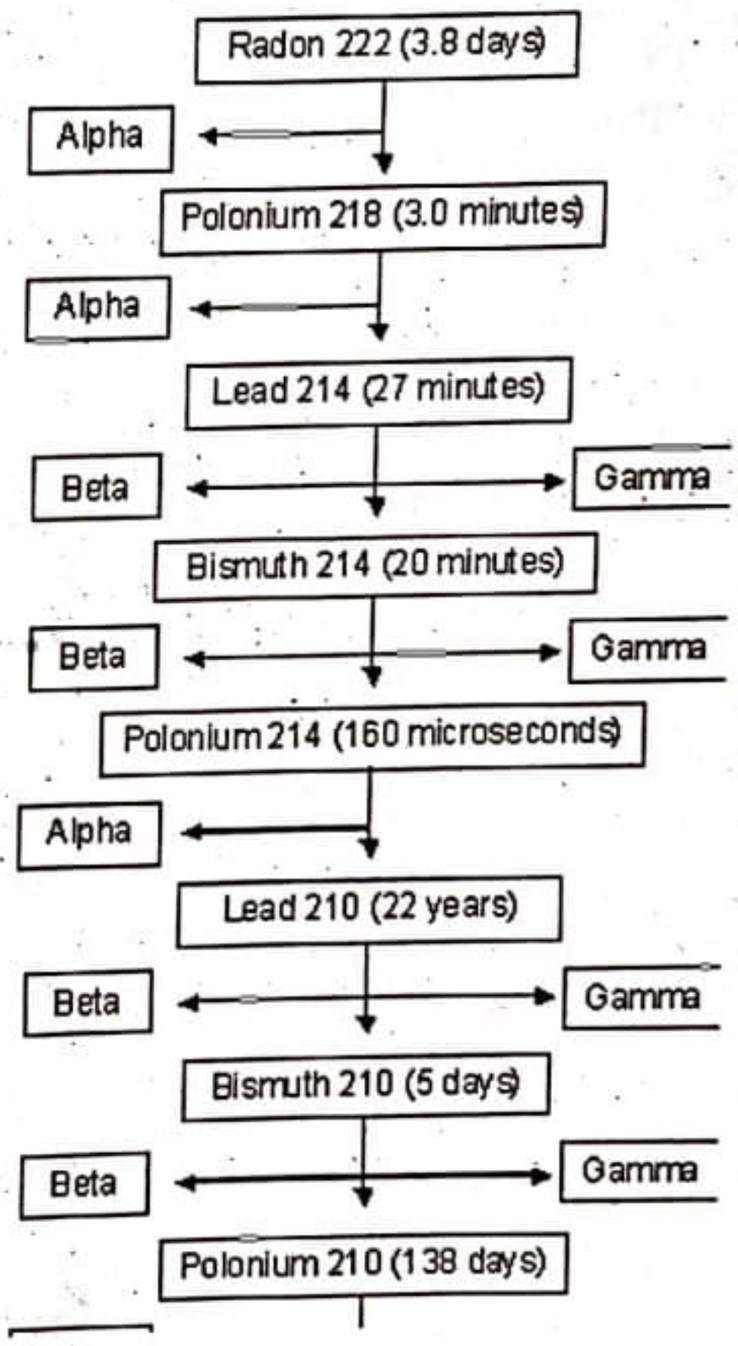
(ii) Photoelectric effect

(iii) Pair production.

- The type of interaction depends upon energy range of photon available according to following scheme:

Energy Range	Type of Interaction
E < 0.1 MeV	Photoelectric effect
E = 0.1 MeV to 1 MeV	Compton effect
E > 1.02 MeV	Pair production



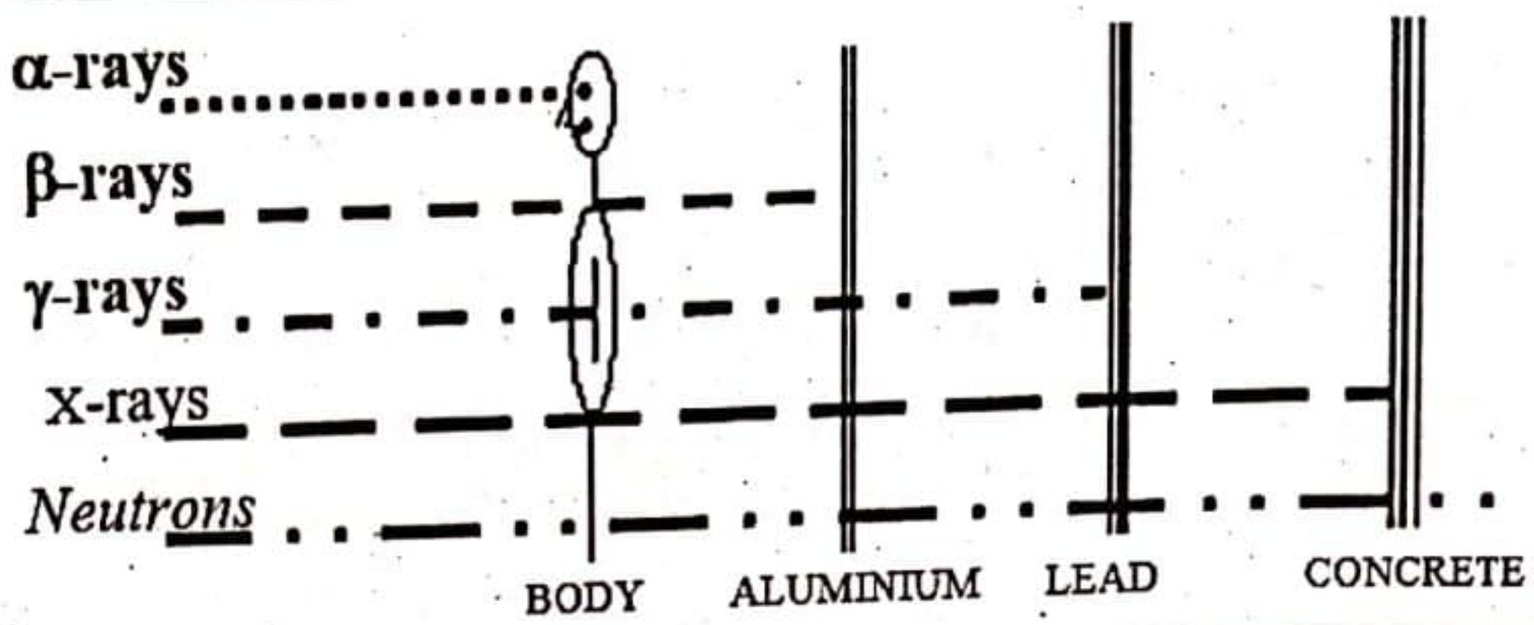


Interaction of Neutrons

- Neutrons are more effective radiation than both α and β rays because they bear no charge as **regard to penetration.**
- When neutron is captured by a nucleus, it results in the formation of a **radioisotope.**
- Neutron causes fission in heavy nuclei.
- Neutron can knock down electrons out of body cells causing **instantaneous death.**

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COMPARISON OF PENETRATION POWER OF VARIOUS RADIATIONS



Radiation	Description	Penetration	Ionization	Effect of e or b field
Alpha (α)	Helium nucleus 2p + 2n Q = + 2 e	Few cm in air Thin paper	Intense, about 10^4 ion pairs per mm.	Slight deflection as a positive charge
Beta (β)	High speed electron Q = -1 e	Few mm in aluminium	Less intense than a, about 10^2 ion pairs per mm.	Strong deflection in opposite direction to E.
Gamma (γ)	Very short wavelength Em radiation	Several cm in lead, couple of m of concrete	Weak interaction about 1 ion pair per mm.	No effect

RADIATION DETECTORS

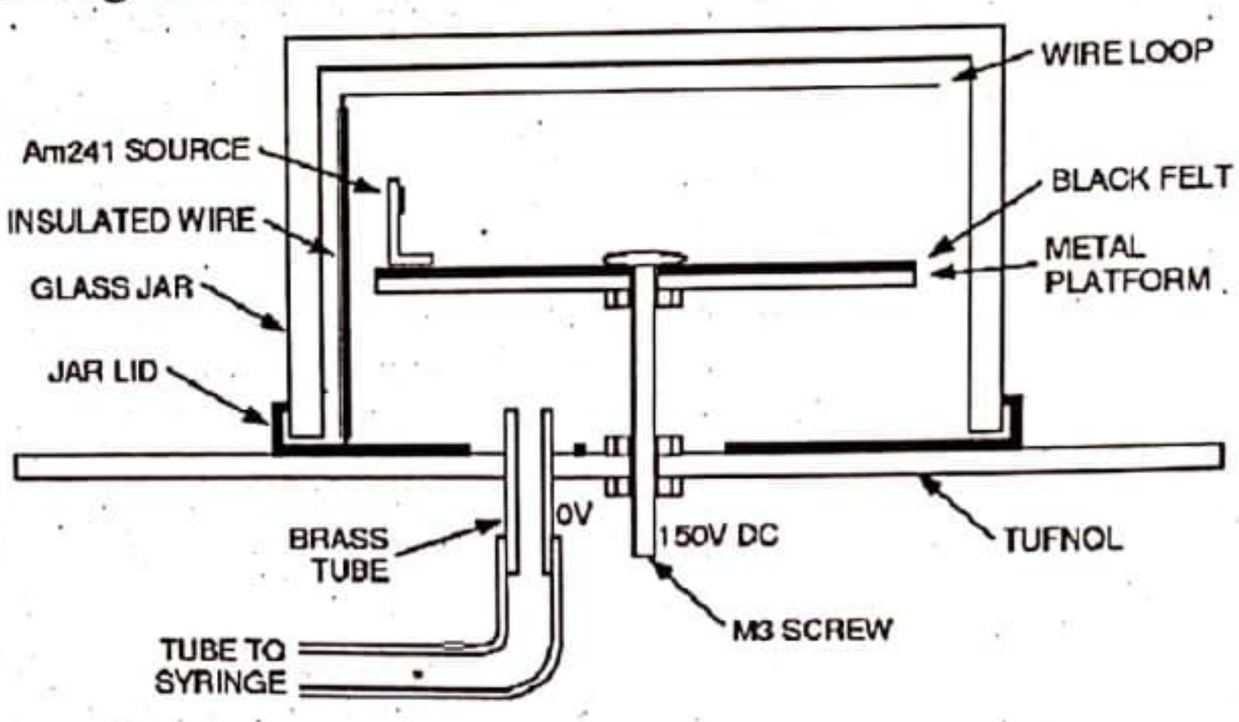
Wilson Cloud Chamber

- C.T.R Wilson in 1911 invented Wilson cloud chamber.
- Wilson cloud chamber is based upon the following principle: -

"Super saturated droplets prefer to condense on ions or dust particles similar to formation of clouds."

Construction

It consists of a circular base metal plate with hole in the center. Above it, is another metal plate with a black felt pad. A Perspex or glass dome fits over the two plates with the source on its top.



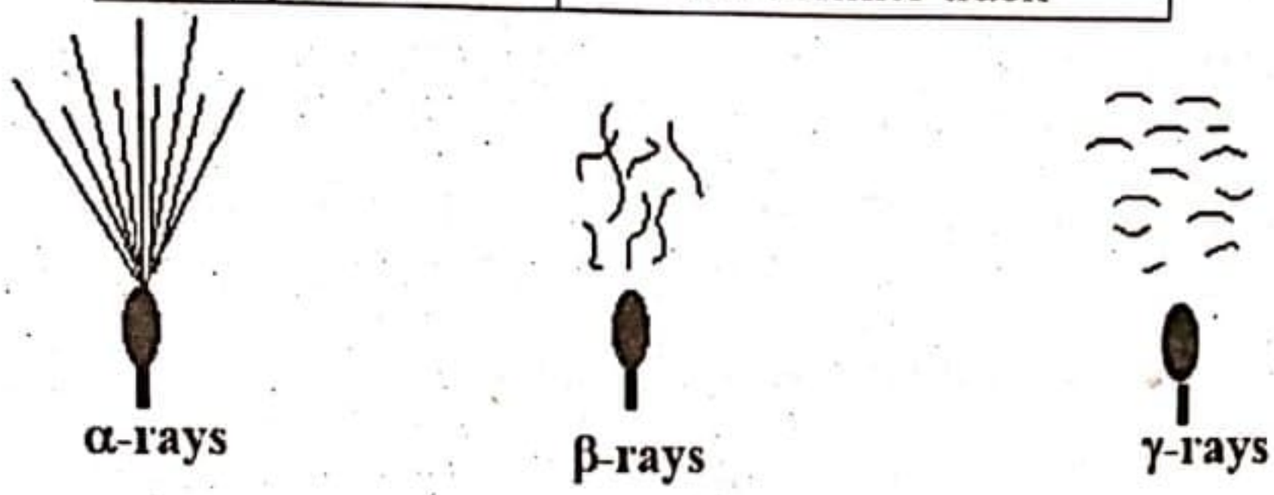
Procedure

Due to adiabatic expansion, the super-saturated droplets are produced. When nuclear radiation enters, it produces ionization and water vapours condense on such ions. They reflect light to make the path of ionizing particles visible. A high-speed camera photographs the track of ionizing particle.

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Track of Ionizing Particle

Name of Particle	Shape of Track
α-particle	Solid and continuous
β-particle	Zigzag and discontinuous
γ-particle	No definite track



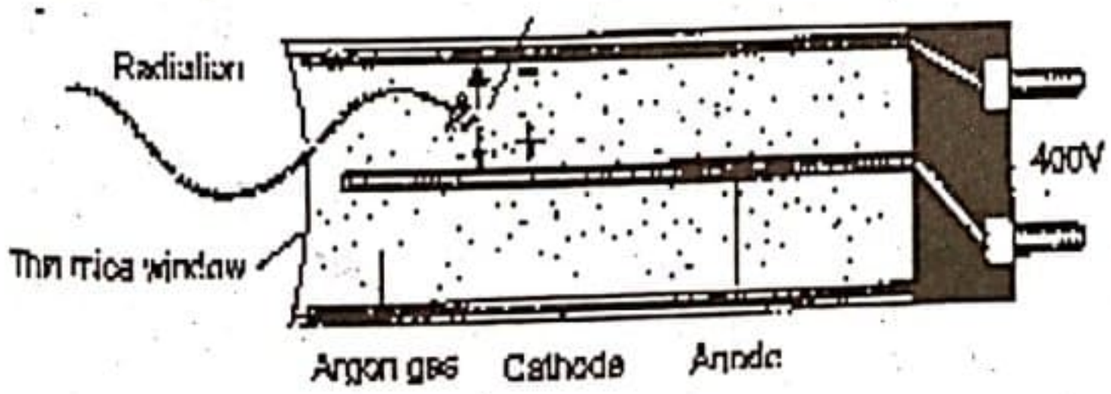
- By applying magnetic field, the α & β particles deviate from its original path.
- By measuring radii of curvature, we can also measure e/m ratio of α & β particles.
- Length of cloud tracks is proportional to energy

Geiger - Muller Counter

- Geiger and Muller invented G.M counter (Geiger - Muller counter).

Construction

G.M counter consists of a metal tube (cathode) containing inert gas (such as argon & alcohol or bromine and neon) at 0.1 atmospheric pressure. There is a thin wire (anode) co-axial with metallic tube.



POINT PONDER

The Geiger Mueller counter is an electronic instrument used for detecting and measuring low level β-particle and γ-ray radiation. It cannot detect α-particles. It is also known as a G-M Counter.

Procedure

(i) When nuclear radiation enters, it produces ionization in halogen gas ions.
(ii) **Positive ions move** towards negative metallic plate while negative ions **towards positive** wire.
(iii) Electrons released by nuclear radiation rush towards the positive wire knocking out electrons from atoms of gas in their way. In this way an **avalanche** of electrons reach the wire and hence current pulse is produced.
(iv) The current pulse is detected across a **resistance of $10^9\ \Omega$.**

Quenching of Discharge

Positive ions on reaching the metal tube pull out electrons. These electrons can excite the atoms, which on returning to ground state emit photons, which then ejects **photoelectrons under photoelectric effect**. To avoid photoelectrons, we do quenching.

Quenching of discharge in G.M counter is attained by following two ways:

(i) Manual quenching: by lowering voltage below critical value of discharge.

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(ii) Self-quenching: by adding bromine gas into principal gas (neon). The mechanism is such that the I:E of bromine is lower than neon, the ions of quenching gas reach the cathode before principal gas ions. When they reach near the cathode, they capture electron and become neutral molecules. Following neutralization, the excess energy of the quenching molecules is dissipated in dissociation of the molecules rather than in the release of electrons from the cathode.

- G.M counter can be used to study β and γ-rays effectively.

Solid State Detector

- Solid State detector is most sensitive detector capable of detecting three α, β & γ-rays.

Construction

Solid State detector mainly consists of reverse biased diode.

Procedure

When radiation falls on the diode, it causes the release of electrons, creating some sort of conduction path. The voltage caused due to flow of electrons is measured.

Advantages

(i) Compact size
(ii) Very fast detector
(iii) No need of quenching
(iv) Portable
(v) Can detected α, β and γ-rays.
(vi) Low energy utilization (requires 3 eV — 4 eV of energy)

NUCLEAR FISSION

- Otto Hahn and his co-workers discovered nuclear fission accidentally when they were attempting to prepare transuranic elements by bombarding $_{92}U^{235}$ with $_{0}n^{1}$ (slow).
- **Transuranic** elements are those elements that have atomic no. greater than that of uranium (the heaviest natural element) e.g. Np (Z=93), Pu (Z=94) etc.
- There are 30 different ways by which nucleus can undergo **fission** accompanied by 2 to 5 neutrons (average is 2.5 neutrons).
- Fission neutrons are ejected by **daughter or fission fragment**, not by parent nucleus.
- During fission, 99 percent neutrons are ejected in extremely short time and are called prompt neutrons; the remaining 1% are emitted a litter latter. They are called **delayed neutrons.**
- Unstable fission fragments, to become stable, eject delayed neutrons.

Isotopes of Uranium

Ore	Percentage	Half-life
$_{92}U^{238}$	99.38%	4.51×10^{9} years
$_{92}U^{235}$	0.714%	7.1×10^{8} years
$_{92}U^{234}$	0.006%	2.48×10^{5} years

- For fission of $_{92}U^{238}$, $_{0}n^{1}$ of energy 1 MeV is required while for $_{92}U^{235}$, $_{0}n^{1}$ of energy 0.04 eV is required.
- Two common fission reactions for uranium are as follows:

$$_{0}n^{1} + {}_{92}U^{235} \longrightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\ {}_{0}n^{1} + 200\ \text{MeV (Q)}$$

$$_{0}n^{1} + {}_{92}U^{235} \longrightarrow {}_{54}Xe^{140} + {}_{38}Sr^{94} + 2\ {}_{0}n^{1} + 200\ \text{MeV}$$

Where Q is called energy of nuclear reaction.

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Types of Fission

(i) **Controlled Fission Chain Reaction**

In this reaction only one neutron, out of all the neutrons created in one fission reaction, becomes the cause of further fission reaction. It is the underlying principal of nuclear reactor.

(ii) **Critical Mass**

Such a mass of uranium in which one neutron, out of all the neutrons produced in one fission reaction, produces further fission is called critical mass.

(iii) **Uncontrolled Fission Chain Reaction**

If the mass of uranium is much greater than the critical mass, then the chain reaction proceeds at a rapid speed and a huge explosion is produced. Atom bomb works at this principal

- Fermi carried out first **controlled fission** in 1942.
- Fission of $_{92}U^{235}$ atom releases 10^8 times as much energy as is released by $_6C^{12}$ atom in ordinary furnace.

1 kg of $_{92}U^{235}$ contains $\Rightarrow$ $(1000\ g/235) \times 6.023 \times 10^{23} = 25.6 \times 10^{23}$ atoms

We know that,

1 atom of $_{92}U^{235}$ gives $\Rightarrow$ 200 MeV

$\therefore$ 1 kg of $_{92}U^{235}$ gives $\Rightarrow$ 5.12×10^{26} MeV

We know that,

Time for one fission $\Rightarrow 10^{-8}$ s

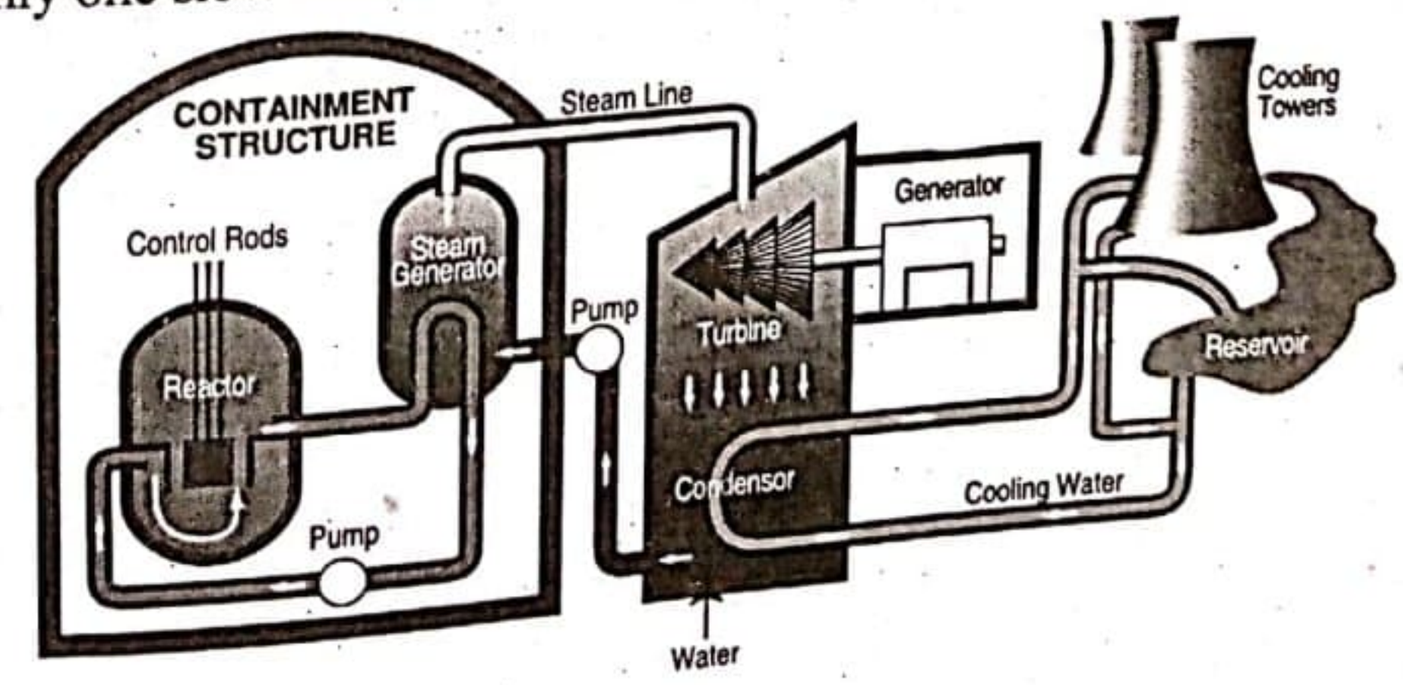
$\therefore$ Time for 60 fissions $\Rightarrow$ 0.6 μs

Thus 5×10^{26} MeV energy is liberated in 0.6μs when 1 kg of $_{92}U^{235}$ undergoes complete fission.

- Plutonium-239 and uranium-233 are also being used as fuel.

NUCLEAR REACTOR

- Fission chain reaction can be controlled in a device called **nuclear reactor.**
- Nuclear reactor works according to principle that the environment of nuclear reactor is controlled in such a way that only one slow neutron takes part in fission process at a time.



Parts of Nuclear Reactor

(i) **Fuel Rods:** $_{92}U^{235}$ is used as fuel. In this fuel the quantity of $^{235}_{92}U$ is increased from 2 to 4 percent.

(ii) **Control Rods:** Ba or Cd rods absorb neutrons efficiently.

(iii) **Moderator:** to slow down neutrons usually **graphite**

(iv) **Heat Exchanger:** to convey the energy produced for the sake of use.

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(v) **Cooling System:** to avoid over **heating**

(vi) **Core:** consists of fuel, control rods and moderator.

(vii) **Biological Shield:** to prevent scattering of **harmful radiations.**

(viii) **Breeding:** Breeder nuclear reactor is that which prepare its fuel by itself.

Types of Nuclear Reactors

(i) Thermal reactor

(ii) Fast reactors

Thermal Reactor

- Neutrons must be **slowed down** to thermal energies to produce fission.
- In this reactor U^{235} is used as fuel.

Fast Reactors

- Fast neutrons are used to strike $_{92}U^{238}$ producing $_{93}Np^{239}$ and then $_{94}Pu^{239}$. This type of reactor is liquid metal fast breeder reactor **(LMFBR)**

Liquid Metal Fast Breeder Reactor

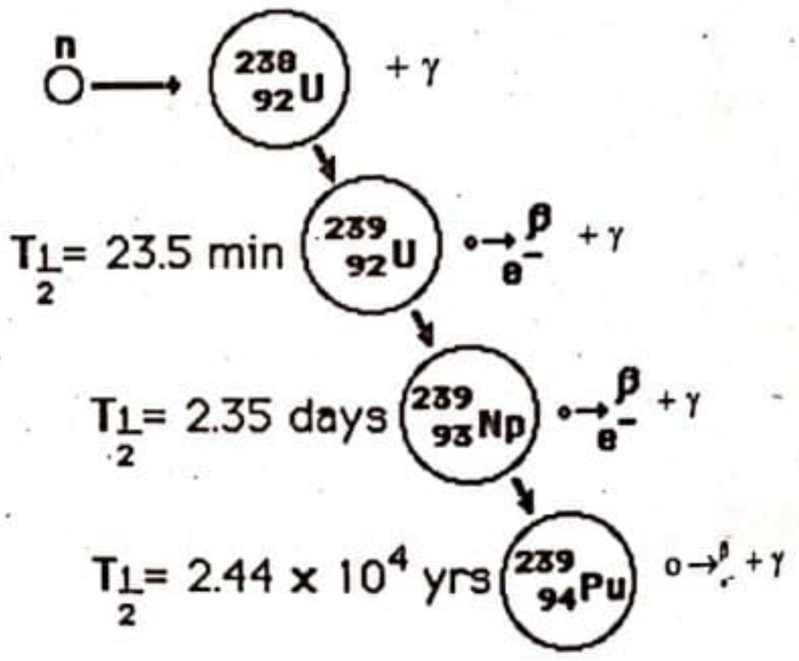
- LMFBR produces plutonium according to following scheme:

$$_0n^1 + {}_{92}U^{238} \longrightarrow {}_{92}U^{239} \text{ (unstable)} + \gamma \quad (T_{1/2} = 23.5 \text{ minutes})$$

(fast)

$$_{93}Np^{239} + {}_{-1}\beta^\circ + \gamma \quad (T_{1/2} = 2.4 \text{ days})$$

$$_{94}Pu^{239} + {}_{-1}\beta^\circ + \gamma \quad (T_{1/2} = 24400 \text{ years})$$



Differences between Thermal Reactor and LMFBR

Conventional Reactor	LMFBR
Moderator	No moderator
Coolant is ordinary water or gas	Na is coolant
Run continuously	Requires maintenance after 15 days
Uses $_{92}U^{235}$ as fuel	Uses $_{92}U^{238}$ as fuel

NUCLEAR REACTIONS & NUCLEAR FUSION IN THE SUN

- Fusion reaction is production of heavy nucleus by nuclear reaction of light nuclei

There are two types of reactions

(i) D-D Reaction

$$_1^2H + {}_1^2H \longrightarrow {}_2^4He + 24 \text{ MeV}$$

$$_1^2H + {}_1^2H \longrightarrow {}_1^3H + {}_1^1H + 4.0 \text{ MeV}$$

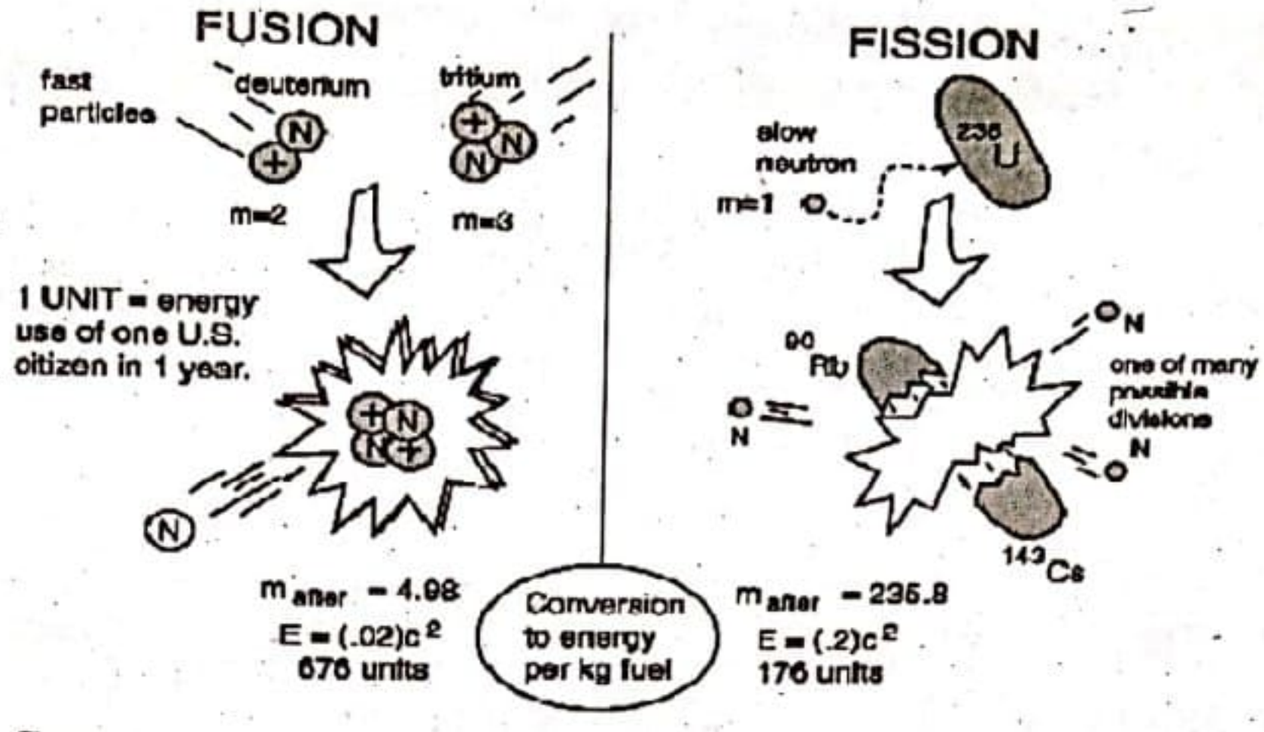
$$_1^2H + {}_1^2H \longrightarrow {}_2^3He + {}_0^1n + 3.3 \text{ MeV}$$

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(ii) D-T Reactions

$$_1^2H + _1^3H \longrightarrow _2^4He + _0^1n + 17.6\ MeV$$

- Fusion is more energetic than fission.



Nuclear Reaction in the Sun

The source of energy in the sun is nucleus fusion

- The temperature of its core is about 20 million degrees Celsius and its surface temperature is about 6000 degrees Celsius. Its energy is due to fusion reaction called p-p reaction.

Proton-Proton Cycle

$$_1H^1 + _1H^1 \longrightarrow _1H^2 + \beta^+ + \upsilon$$

$$_1H^2 + _1H^1 \longrightarrow _2He^3 + \gamma$$

$$_2He^3 + _2He^3 \longrightarrow _2He^4 + _1H^1 + _1H^1 + Energy$$

- Stars like sun maintains their shape and pressure due to radiation pressure.

COMPARISON OF ISOTOPES, ISOBARS & ISOTONES

	Isotopes	Isobars	Isotones
Atomic Number	Same	Different	May or may not be the same
Mass Number	Different	Same	May or may not be the same
No. of Neutrons	Different	May or may not be the same	Always same

RADIATION EXPOSURE

- Radiations can damage **living tissues**. The degree of damage and kind of damage depend on type, energy and dose of radiation. Incident radiations ionize the body cell, and then change biochemistry of the cell. A damaged cell **may die** or **begins to work in wrong way** e.g. sometimes radiation changes the chemistry of cells in such a way hat they begin to reproduce rapidly leading to a **condition called cancer.**
- Damage to ozone layer is done through following sources: -

(i) **Chemical** industry
(ii) **Nuclear** tests
(iii) **CFC (chlorofluorocarbons)**
(iv) **Aerosol** sprays and plastic foam industry

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- Some radiation in the environment is added by human activates like diagnostic x-ray, nuclear facilities, hospitals, research and industrial establishments, colour television, luminous watches and tobacco leaves.

EFFECTS OF RADIATIONS

Effects of radiations are of two types:

(i) Somatic Effect:

These are direct effects on body e.g. **skin burns, loss of hair**, ulceration, stiffening of lungs, drop in white blood cells and contraction in eyes etc.

These effects can be cured if the dose is small.

(ii) Genetic Effects:

These affect (alter) the chemistry of genes and cause mutation e.g. **cancer, different syndromes etc.**

These effects are incurable and pass on to future generation.

(iii) Biological Effects

Absorbed Dose

Absorbed dose D defined as the energy E absorbed from ionizing radiation per unit mass m of the absorbing body. $D = \frac{E}{m}$

Its SI unit is gray (Gy). $1\ Gy = 1\ J\ kg^{-1}$

An old unit is rad, an acronym for radiation absorbed dose.

$$1\ rad = 0.01\ Gy$$

Equal doses of different radiations do not produce same biological effect. The effect also depends on the part of the body absorbing the radiation.

- For the same absorbed dose, α -particles are 20 times more damaging than X-rays
- Neutrons are particularly more damaging to eyes than other parts of the body.

Equivalent Dose

It is defined as the product of absorbed dose and RBE (relative biological effectiveness)

$$1\ Sv = 1\ Gy \times RBE \quad \text{(SI Unit)}$$

Old Unit

$$1\ rem = 0.01\ Sv$$

UNIT OF RADIOACTIVITY

- Becquerel (Bq)
  1 Bq = one disintegration per second
- Curie (Ci)
  $1\ Ci = 3.7 \times 10^{10}\ Bq$

BIOLOGICAL AND MEDICAL USES OF RADIATIONS

- C-14 is one of useful tracer that can help in the understanding of **photosynthesis.**
- I-131 and Na-24 are used to check **cracks in pipes.**
- Radiation therapy is a process of destruction of cancerous cells deep into body e.g. Co-60 & I-131 are **used to treat cancers.**
- Tumors are treated by **γ-rays.**
- Radio processes in space give information about **structure of stars.**

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- When ethylene is radiated with γ-rays, it is polymerized into polyethylene, which is used to **produce soft and flexible products.**
- **Sterilization** is a process of killing of germs with β-particles or γ-rays.
- Radiation treatment can **preserve food** and other eatables.
- γ-gauges are used for preparing or measuring the thickness of high density and thicker materials such as **steel, Al & rubber**. In such gauges, Co-60 is used as γ-rays source.
- β-gauges are used for preparing or measuring the thickness of thin sheets of low density materials e.g. paper. In **such gauges, Sr - 90 is used as a β-rays source**
- **Radiography** is employed to check cracks of cavities in metal casting, faults in welding & heavy machinery.
- Ratio of C-14 to C-12 found in dead matter is a measure of time span **since death.**
- β particle is used for **superficial skin therapy.**
- α particle is used for deep **skin therapy.**
- Activation analysis (γ-ray energy measurement) is applied to determine concentration of elements in a given sample and to estimate corrosion and wear of machinery.
- Technetium - 99 has given rise to positron emission tomography.
- The ratio of $_{62}Pb^{206}$ — $_{92}U^{238}$ is used to determine age of rocks.

Interesting Considerations

- The age of **pyramids** is 4500 years.
- By Ar-40, we can measure dates as back as one million years ago.
- Amino acids have been discovered on **meteorites.**
- To destroy a tumor, we place small pellets of radionuclide near it e.g. radon seed (radon in miniature gold capsule). After destruction of tumor, we remove them.
- Different radioisotopes accumulate in specific parts of body e.g.

Radioisotopes	Site of Accumulation
Iodine	Thyroid gland
Cobalt	Liver
Phosphorus & Calcium	Bones

Radiography

- γ-rays radiographs are used in **medical diagnosis**
- Cracks and cavities in castings or pipes are detected by γ ray scanning.
- The gamma camera is used to detect γ radiations from sites in the body where a γ -emitting isotope is located.

BASIC FORCES OF NATURE

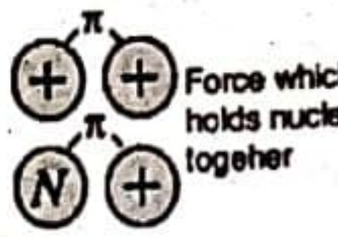
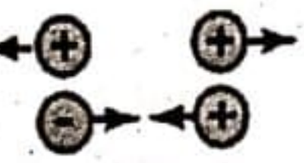
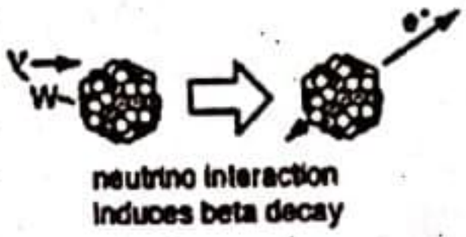
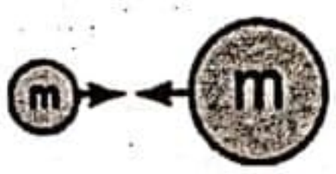
There are now four basic forces in nature.

(i) Gravitational force (long range)
(ii) Electromagnetic force (long range)
(iii) Strong nuclear force **(short range, 10^{-15} m) attractive**
(iv) Weak nuclear force **(short range, 10^{-17} m) repulsive**

In 1979, the physics noble prize was conferred on Glashow, Weinberg and Abdus Salam for the unification of electromagnetic and weak forces.

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Fundamental Forces

		Strength	Range (m)
Strong	 Force which holds nucleus togeher	1	10^{-15} (diameter of a medium sized nucleus)
Electro-magnetic		$\frac{1}{137}$	Infinite
Weak	 neutrino interaction induces beta decay	10^{-6}	10^{-18} (0.1% of the diameter of a proton)
Gravity		6×10^{-39}	Infinite

BUILDING BLOCKS OF MATTER

Subatomic particles are divided into three groups

(i) Photons

(ii) Leptons (electron, muons and neutrinos)

(iii) Hadrons

There are two types of hadrons

(i) Baryons (the particles equal in mass or greater than protons are called baryons e.g. protons and neutrons)

(ii) Mesons (the particles lighter than proton e.g. π mesons)

A pair of quark and anti-quark makes a meson and 3 quarks make a baryon.

- Elementary particles are the basic **building blocks**.
- All photons and Leptons are elementary particles.
- Hadrons are not elementary particles.
- Hadrons are composed of elementary particles called quarks.
- Matter belongs to either lepton group or quark groups.

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