LECTURE NOTES

ENGINEERING PHYSICS

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WORK :

Definition: Work done by a constent force acting on a body F is defined as equal to the megnitude of the force F multiplied by the displacement s in the dir^n of the force.

$$\boxed{W = F \cdot s}$$

$$\boxed{W = (F\cos\theta) \times s}$$ where θ is the angle b/w F and s.

$$\boxed{W = \vec{F} \cdot \vec{s}}$$

* Work is a scalar quantity.
  S.I unit → joule (J), CGS unit → erg.
  1 J is the work done by a force of 1N acting through a distance of 1m in the direction of force.

$$\boxed{1\,J = 10^7\ erg}$$

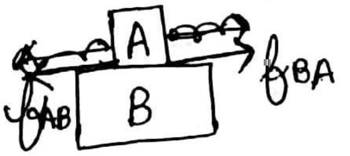
* Depending upon the value of θ, the work done may be +ve ($90° > \theta > 0°$), zero ($\theta = 90°$) or -ve ($270° > \theta > 90°$).

Friction :-

→ It is a force which opposes the relative motion between two bodies.

→ Frictional force acts tangentially along the contact.

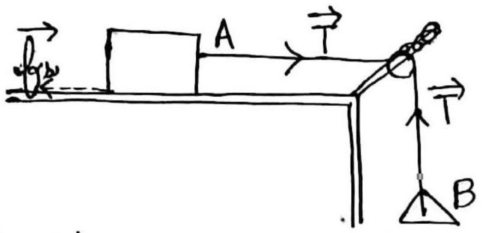
→ Frictional force exist in pair.



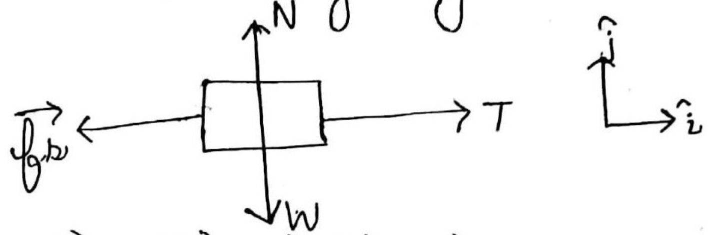
Suppose there are 2 bodies A and B. If A is pulled in the forward dir^n, then w.r.t. B A is moving forward. So B will excert frictional force on A in the backward dir^n along the contact tangentially. So when A is moving forward it appears to it that B is moving backward so A will excert frictional force on B in the forward dir^n.

Static Friction

The force of friction that arises b/w 2 surfaces in contact when there is no relative motion b/w the surfaces is called static friction



Free-body diagram



The block continues to be at rest as long as $\vec{f_s} = -\vec{T}$
When weight is added to the pan T increases, hence f_s increases.

$\vec{F}_{act} = \vec{f_s} + \vec{T} + \vec{N} + \vec{W} = 0$
$\Rightarrow -f_s\hat{i} + T\hat{i} + N\hat{j} - W\hat{j} = 0$
$\Rightarrow f_s = T$.
and $N = W =$ Weight of the block.

Laws of static friction

i) The force of static friction is self-adjusting and increases upto a limiting value called force of limiting friction (f_L).

ii) The $f_L \propto$ normal force.

$f_s|_{max} = f_L = \mu_s N$ $\mu_s \rightarrow$ coefficient of static friction.

Its value depends on the nature of the material and roughness of the surfaces in contact.

Coefficient of static friction for given pair of surfaces may be defined as the ratio of the force of limiting friction to the normal force acting on the contact surface.

iii) So long as the normal force N is const. the force of limiting friction does not depend on area of contact.

iv) The actual force of static friction may be smaller than ~~that~~ $\mu_s N$ & its value depends on other forces acting on the body. i.e. $f_s \leq f_s|_{max} (= \mu_s N)$.

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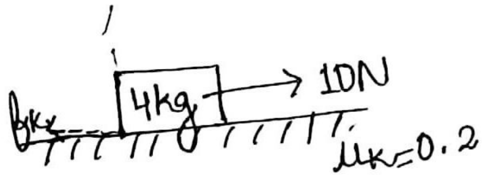
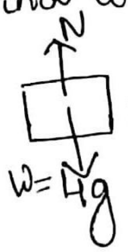
2 types
1) Kinetic friction - relative motion is there (motion)
2) Static " - when tendency of relative motion is there (rest)

Kinetic Friction (f_k)

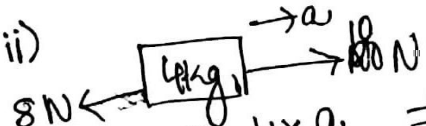
① relative motion
② constant (doesn't depend on the speed of relative motion)
f_k = constant
③ $\boxed{f_k \propto N}$ N = normal reaction
$\boxed{f_k = \mu_k N}$ μ_k = coefficient of kinetic friction — depends on surfaces which are in contact — value found experimentally
④ Direction: → such that it opposes relative motion.

Q)
i) Find frictional force
ii) Find a of the block.



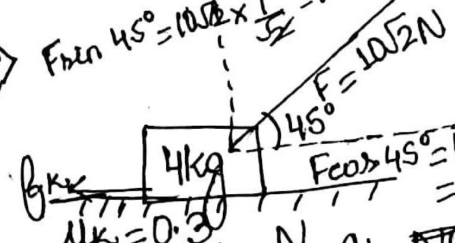


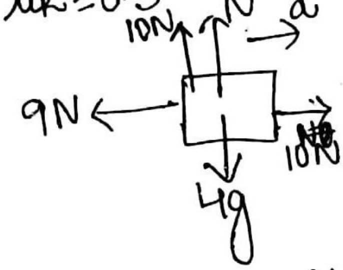
$N = W = 4g = 4 \times 10 = 40$
i) $f_k = \mu_k N = 0.2 \times 40 = 8N$

ii)


$10 - 8 = 4 \times a \Rightarrow 4a = 2 \Rightarrow a = \frac{2}{4} = 0.5\,m/s^2$.

Q)
i) Find N
ii) Find f_k
iii) Find a.

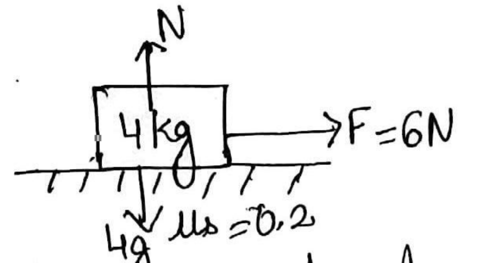




i) $N + 10 = 4g = 40 \Rightarrow N = 40 - 10 = 30$
ii) $f_k = \mu_k N = 0.3 \times 30 = 9N$.
iii) $10 - 9 = 4a \Rightarrow a = \frac{1}{4} = 0.25\,m/s^2$.

Static Friction

① When there is a tendency of relative motion (rest)
② variable → self-adjusting
③ $0 \le f_s \le F_{limiting}$
$\boxed{F_{limiting} = \mu_s N}$ μ_s = coefficient of static friction
④ Dirn → opposite to relative motion

Q) 

Find frictional force and $\vec{a}$ ~~Body~~.

* Body moves only if applied force ($F_{applied}$) > max. static friction ($F_{limiting}$)

$F_{limiting} = \mu_s N = 0.2 \times 4 \times 10 = 8N$

$F_{applied} = 6N < F_{limiting} = 8N$. So body is at rest.

Rest → friction = $F_{applied}$

$F_s = 6N$.

Kinetic Friction

When 2 bodies in contact moves w.r.t. each other, rubbing the surfaces in contact, the friction b/w them is called kinetic friction.

Laws of kinetic friction :-

i) The magnitude of kinetic friction is proportional to the normal force acting b/w 2 bodies.

i.e. $f_K = \mu_K N$. $\mu_K = \frac{f_K}{N}$.

i) So long as the normal force N remains const., the force of Kinetic friction does not depend on the area of contact.

iii) The force of kinetic friction is almost independent of the relative speed of the sliding bodies.

Methods to reduce friction

i) By polishing the surfaces the surfaces

ii) By using lubricants.

iii) By using ball, bearings

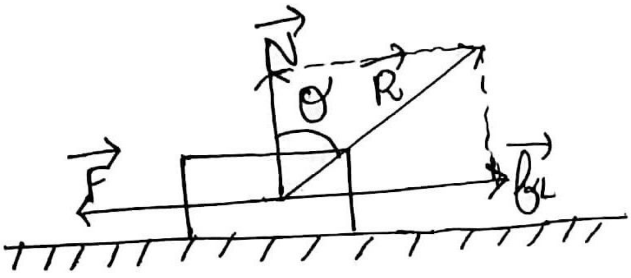
iv) By streamlining the body. For example pin pointed shape has less friction.

Angle of friction

The angle made by the resultant of limiting friction 'f_L' and the normal force N with the normal force 'N' is called angle of friction

$$\tan\theta = \frac{f_L}{N} = \mu_s$$

The coefficient of static friction is equal to the tangent of the angle of friction.



Advantages of friction

i) We can hold a pen & write due to friction b/w finger tip and pen surface.

ii) A nail can be fixed in a wall due to the friction b/w wall and nail surface.

iii) We are able to walk on road due to friction.

iv) We are able to stop a moving vehicle by applying brakes due to friction.

v) A vehicle can take a turn on a level road due to friction.

Disadvantages of friction

i) It causes wear & tear in the moving parts of the machineries

ii) Energy has to be spent against friction.

iii) It slows down motion of moving objects.

UNIT-6 OSCILLATIONS & WAVES

Simple Haromonic Motion (SHM)

1. **Periodic motion** - A motion which repeats itself again & again at regular intervals of time is called periodic motion.

e.g. i) motion of earth around sun
ii) motion of e^- around nucleus
iii) motion of hands of a clock.

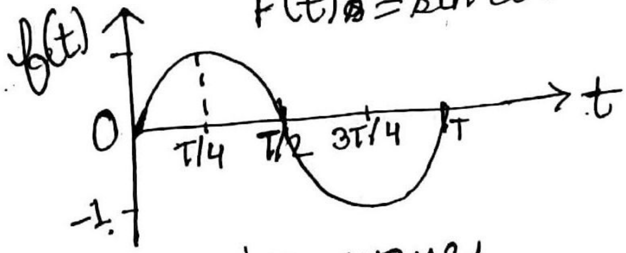
2. **Oscillatory/vibratory motion** - A motion that repeats again & again about its mean position of rest such that it remains confined within well-defined limits (called extreme positions) on either side of the equilibrium (mean) position is called oscillatory motion.

eg. i) motion of a pendulum
ii) motion of a swing.

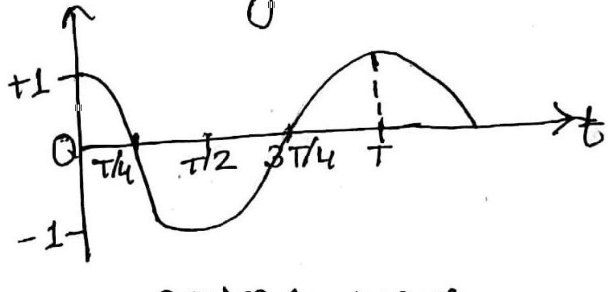
Types of periodic function

i) **Harmonic function** - Periodic functions which are represented by cosine & sine functions of period T are called ~~periodic~~ harmonic functions.

$F(t) = \sin \omega t$ $\qquad$ $g(t) = \cos \omega t$

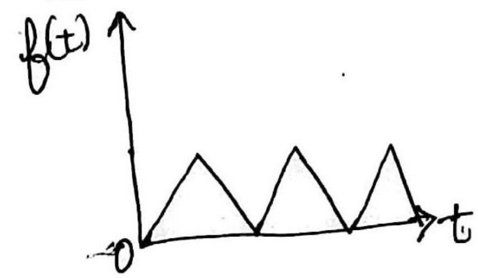


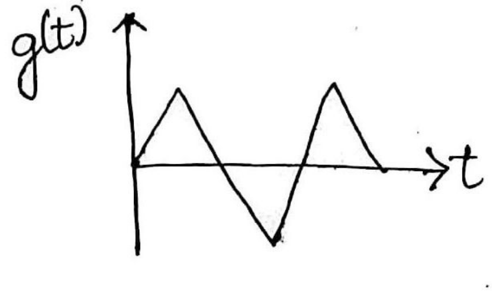
sine wave



cosine wave

ii) **Non-harmonic functions**: Periodic functions which are not represented by sine and cosine functions are called non-harmonic functions.



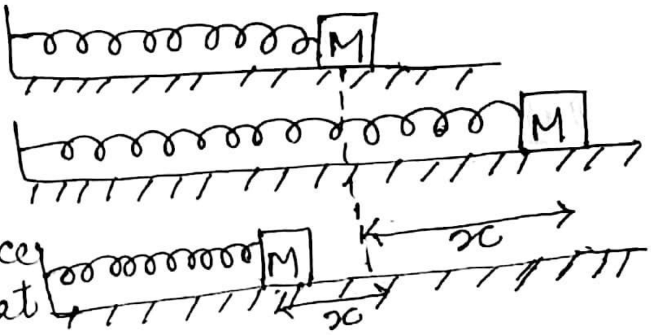


Simple Harmonic Motion (S.H.M.)

A particle is said to have S.H.M. if it moves to and fro about a fixed point such that its acceleration at any instant is directly proportional to the displacement but direction of acceleration is opposite to the direction of displacement.

e.g. - motion of spring on frictionless surface when its one end is fixed and other is in motion.

~~Here~~ $\cancel{\vec{a} \propto -\vec{x}}$



If the particle is disturbed from its equilibrium position so that its displacement is x, then for the particle to perform S.H.M., a force F must act on the particle, such that

$$F \propto -x$$

or $\boxed{F = -kx}$ —— (1)

where k is a restoring force known as the force constant. From the above relation, we see if displacement is +ve then the force is -ve and vice-versa. The force F is known as restoring force.

If the mass of the particle is m, then due to the appearance of force F, the particle will experience an acceleration a given by

$$a = \frac{F}{m} = \frac{-kx}{m}$$

or $\boxed{a = -\omega^2 x}$ —— (2)

where $\omega^2 = \frac{k}{m}$ —— (3)

Here ω^2 is a +ve constant.

Characteristics of SHM:

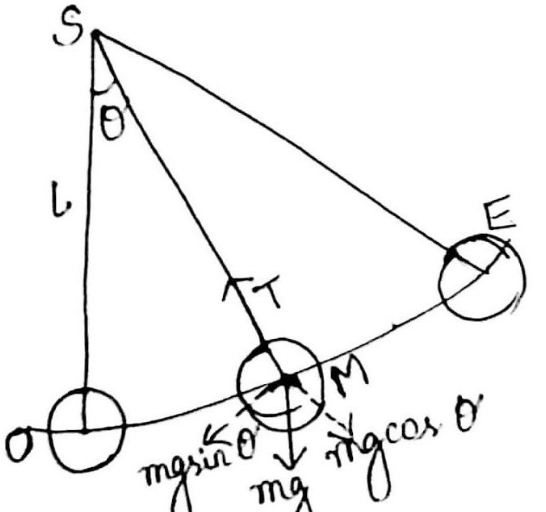
1) It is a motion in a straight line.
2) Force as well as acceleration are proportional to displacement.
3) Force as well as acceleration are directed opposite to displacement.
4) The motion is oscillatory.
5) The time period of oscillation is independent of amplitude it simply depends on the force constant and mass of the oscillating body.

Examples of Simple Harmonic Motion

1) **Motion of a Simple Pendulum**: When the simple pendulum is displaced from the equilibrium position O to some other position M, then an unbalanced force given by

$F = -mg\sin\theta$

acts which is directed towards the equilibrium position. Here m is the mass of the bob suspended by a long string of length l and θ is the angle.



Motion of pendulum

As a consequence of the unbalanced force, as the displacement OM is not large, θ is small so

$$\sin\theta \cong \theta = \frac{OM}{SO} = \frac{x}{l}$$

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

where $x = OM$ is the linear displacement. ~~and~~ since g/l is the const & acceleration is directed towards the equilibrium position, the motion is SHM and the frequency and time period can be obtained from the fact that the ratio of instantaneous acceleration and instantaneous displacement gives ω^2.

Thus, $\omega = 2\pi f = \sqrt{\frac{g}{l}} = \frac{2\pi}{T}$.

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

2) Vibration of a mass-spring system:

Consider a spring loaded with a body of mass m. Whenever a spring is stretched (or compressed) by an amount l a restoring force proportional to ~~strength~~ stretching is produced i.e., if force generated is F, then

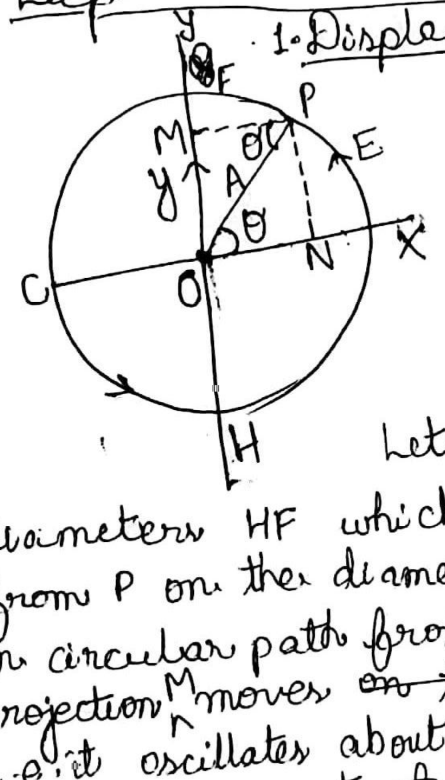
$$F \propto -l$$

or $F = -kl$

where k is a constant known as spring constant.

Expressions in Simple Harmonic Motion

1. Displacement:



Consider a particle moving in a uniform circular motion in a circle EFGH of radius A. Let its linear speed be V & its angular speed be ω. If the period of revolution is T, then

$$\omega = \frac{2\pi}{T} \quad \text{——— (1)}$$

Let us consider projection of one of the diameters HF which is along Y-axis. The foot of the perpendicular from P on the diameter HF is M. Let the particle starts its journey on circular path from E. As the particle P moves its journey its projection M moves ~~on the circular path, its~~ up and down along Y-axis. i.e. it oscillates about its mean position O.

The displacement ~~of~~ OM of the particle M from O is given by

$$OM = OP \sin\theta$$

where $\theta = \angle EOP$.

If time is measured from the instant P is at E (i.e. M is at O), then the angle turned θ in t seconds by the particle moving with angular velocity ω is given by

$$\theta = \omega t$$

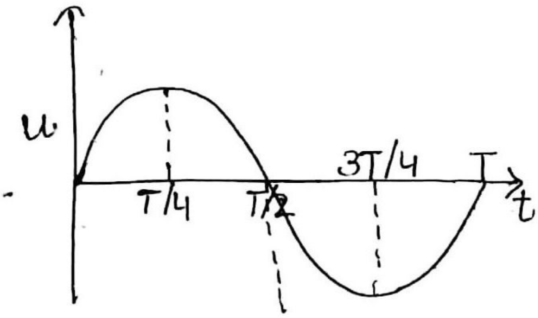
Hence, on writing $OM = y$ and $OP = A$.

$$\boxed{y = A \sin \omega t} \quad \text{—— (1)}$$

This equ^n gives the displacement y of a particle M performing SHM along Y-axis.

$$y = A \sin \frac{2\pi t}{T} \quad \text{—— (2)} \qquad \left[\because \omega = \frac{2\pi}{T}\right]$$

t	0	T/4	2T/4	3T/4	T
u	0	A	0	-A	0

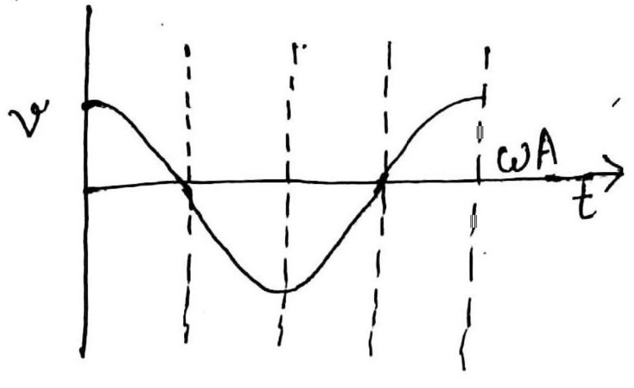


2. Velocity: The velocity of the particle M at any instant can be obtained by differentiating the displacement equ^n w.r.t time t.

$$v = \frac{dy}{dt} = \frac{d}{dt}(A \sin \omega t) = \omega A \cos \omega t \quad \text{—— (1)}$$

$$\text{or } v = \omega A \cos \frac{2\pi t}{T} \quad \text{—— (2)}$$

t	0	T/4	2T/4	3T/4	T
v	ωA	0	ωA	0	ωA



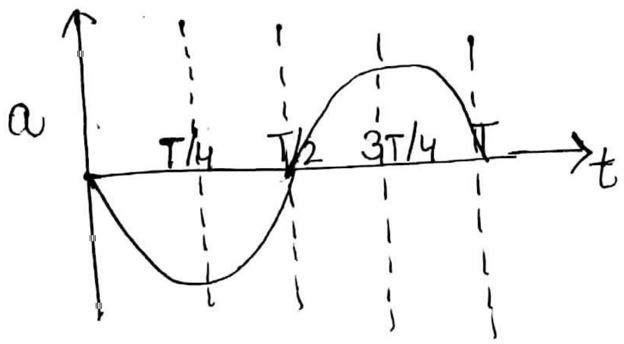
3. <u>Acceleration</u>: The rate of change of velocity gives acceleration.

$$a = \frac{dv}{dt} = \frac{d}{dt}(\omega A \cos \omega t) = -\omega^2 A \sin \omega t \quad (1)$$

As $y = A \sin \omega t$, so

$$a = -\omega^2 y \quad (2)$$

t	0	T/4	2T/4	3T/4	T
a	0	$-\omega^2 A$	0	$\omega^2 A$	0



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<u>Wave Motion</u>

A wave implies propagation of disturbance in some physical quantity of the medium from one place to another.

A wave involves propagation of a physical condition in space and time. For example, when we pluck a taut string at some point, a pulse travels on the string which represents a transverse displacement travelling on the string originating from the point of plucking.

<u>Classification of Waves</u>

(1) <u>Nature of disturbance being propagated</u>

On the basis of the physical quantity being propagated the waves are classified under the following:

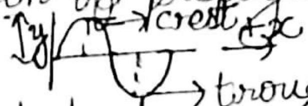
(i) <u>Mechanical waves</u>: These waves are produced because of the deformation of the elastic medium. The particles of the medium vibrate. These waves need a physical medium for their propagation. Ex. - sound waves, water waves.

ii) <u>Electromagnetic waves</u>: In this type of waves electric and magnetic field vectors propagate in space. These waves do not require any material medium to propagate. Ex. - radio waves, microwaves, light waves.

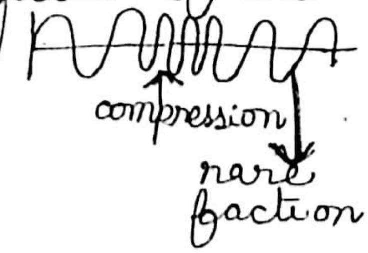
(2) <u>Direction of vibration and direction of wave propagation</u>

On the basis of direction of vibration the waves are classified as:

(i) <u>Transverse waves</u>: In transverse waves the vibratory motion is at right angles to the direction of propagation of the wave. Ex. - waves on string.

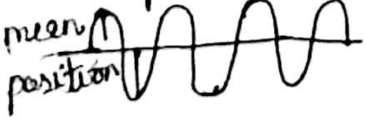


(ii) <u>Longitudinal waves</u>: In a longitudinal wave the vibratory motion takes place in the direction of propagation of the wave. Ex. - waves on springs, sound waves.

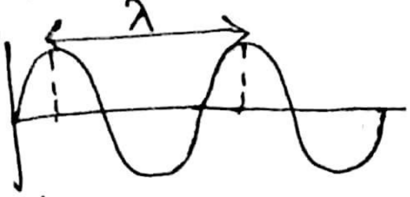


<u>Wave Parameters</u>:

1. <u>Amplitude</u>: The maximum displacement of the particle either above or below from the mean position is called amplitude. S.I. unit - m.

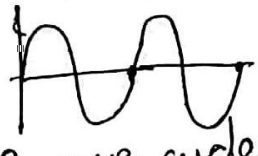


2. <u>Wavelength</u>: In transverse wave the length of successive crest and trough or in longitudinal wave the length of successive compression and rare faction is called wavelength. It is denoted by λ. S.I. unit - m



transverse wave

3. <u>Time period</u>: Time taken by the oscillating body to complete 1 wave cycle is called time period. It is denoted by T. S.I. unit - sec.



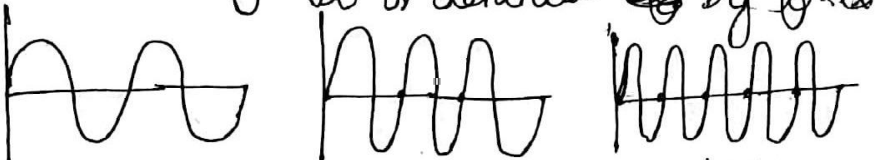
2 wave cycles

~~time = 1 sec~~

~~T= 2 sec~~

~~If it~~ For e.g. if this wave completes 1 wave cycle /oscillation is 2 sec, then its time period is T= 2sec.

4. <u>Frequency</u>: No. of wave cycles /oscillations completed in 1sec. It is denoted by f. S.I. unit - hertz.



1sec — 2 wave cycles — 2 Hertz

1sec — 3 wave cycles — 3 Hertz

1sec — 5 wave cycles — 5 Hertz

$$f = \frac{1}{T}$$

<u>Relation between velocity, frequency and wavelength.</u>

Velocity(v) - The distance covered by the wave in 1 sec is called velocity.

$$\text{velocity} = \frac{\text{distance}}{\text{time}} = \frac{\text{wavelength}}{\text{time period}}$$

$$v = \frac{\lambda}{T} = \lambda f \qquad \left[\because \frac{1}{T} = f\right]$$

$$\boxed{v = f\lambda}$$

<u>Ultrasonics</u>

Ultrasonic waves are sound waves of high frequency i.e. above 20 KHz.

Audible frequency of sound - 20 Hz to 20 KHz.

Properties of ultrasonic waves;

1. Frequency of ultrasonic waves is more than 20KHz (20,000Hz)
2. These waves have short wavelength.

$$v = f\lambda$$
$$f = \cancel{20H} \; 20KHz = 20,000 Hz$$
$$v = 348 \, m/s$$
$$\lambda = \frac{v}{f} = \frac{348}{20,000} \cong 0.0017m$$

3. These waves travel long distances without considerable loss of energy.
4. These waves undergo reflection, refraction and absorption when incident on the surface of medium.
5. These waves travel with the speed of sound (348m/s)
6. USW shows negligible diffraction.
7. ~~Sp~~ Speed of propagation of USW increases with increasing frequency.

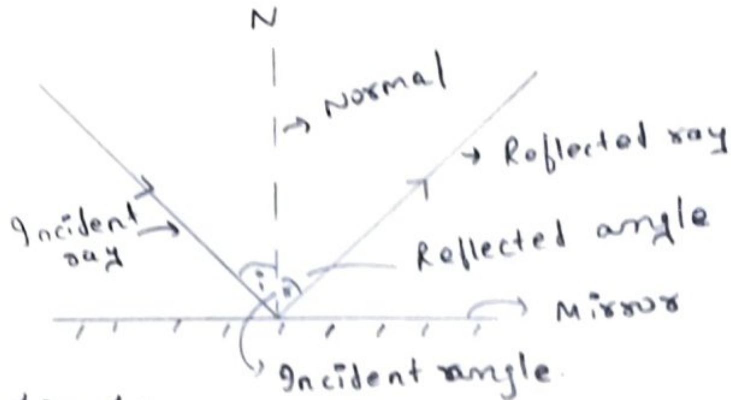
$$v \propto f$$
$$f_1 = 20\cancel{Hz}KHz \qquad f_2 = 30\cancel{Hz}KHz$$
$$V_1 \qquad V_2$$
$$V_2 > V_1$$

8. USW travel with the constant speed in homogeneous (same) medium. When medium changes, the speed changes.

Applications of ultrasonic waves

1. Detection of flaws in metals.
2. To measure the depth of sea.
3. For cleaning and clearing.
4. For direction signaling
5. ~~For~~ Soldering and metal cutting
6. Formation of alloys.
7. Ultrasonics in metallurgy.

Reflection :-



$\angle i = \angle r$

The phenomenon in which a light ray is sent back in to the same medium from which it is coming, on interaction with a boundary is called reflection.

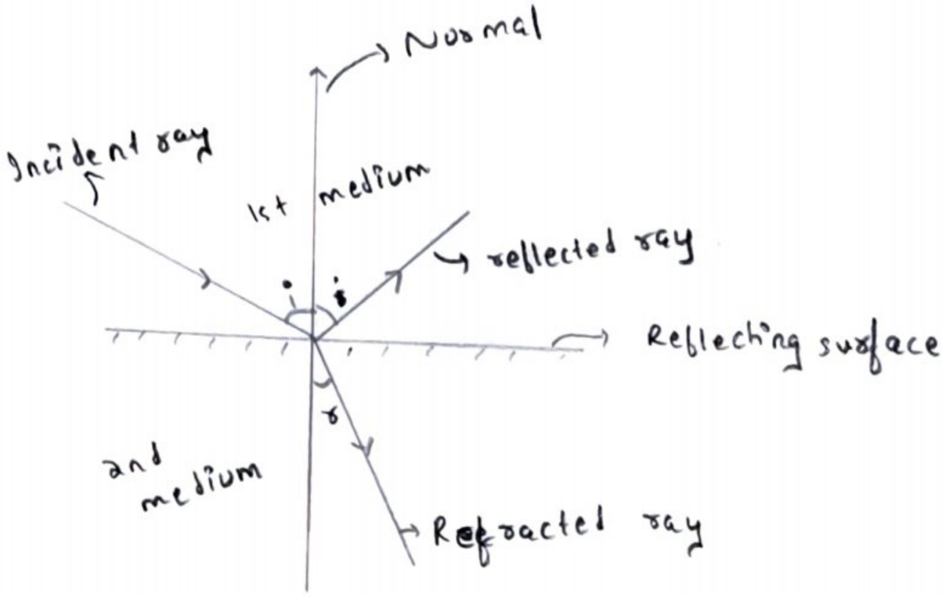
Laws of Reflection :-

There are two laws of reflection :

- The incident ray, the reflected ray and the normal at the point of incidence all three lie in the same place.
- The angle of incidence $\angle i$ is always equal to angle of reflection $\angle r$.

Refraction :

When a beam of light incident on the transparent medium, apart of light gets reflected back in to the first medium, while the rest enter the other medium. Changes at the interface of two medium. This phenomeon is called refraction of light.



Laws of Refraction :-

- The incident ray, the refracted ray and the normal to the interface at the point of incident all the lie in the same place.

- The ratio of the line of the angle of incidence to the line of angle of refraction is constant.

$$\therefore \frac{\sin\angle i}{\sin\angle r} = \mu_{21}$$

where $\mu_{21} \rightarrow$ constant, called refractive intex of 2nd medium with respect to 1st medium.

This law is called as the snell's law of refraction.

Laws of Time period :-

A planet moves around the sun in such a way that the square of its period is proportional to the semimajor axis of its elliptical orbit.

$$T^2 \propto R^3$$

If T_1 and T_2 are the time periods of two planets having R_1 and R_2 respectively.

$$\therefore \quad \frac{T_1^2}{T_2^2} = \frac{R_1^3}{R_2^3}$$

Optics

Ray → A ray is direction of path taken by light. In diagram rays are represented by line with arrows on them.

Beam → A beam is steam of light energy and it is represented by a numbers of rays. The rays either diverging or converging or parallel.

Light → Light is the form of energy by which we see any object around us.

- Speed of light is $3 \times 10^8 m/s$ and denoted by 'C'.
- Light is travelled in a straight line
- Light should be dual Nature
  - * Particle Nature
  - * Wave Nature.

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Mirror → A smooth and highly polished reflecting surface is called mirror.

- Plane mirror → A highly polished plane surface is called plane mirror.

- Spherical mirror → A highly polished curved surface, whose reflecting surface is a cut part of a hollows at glass sphere is called spherical mirror.

Spherical mirrors are of two types.

- Concave mirror :

A spherical mirror whose bent in surface is reflecting surface, is called concave mirror.

- Convex mirror :

A spherical mirror whose bulging surface is reflecting surface is called convex mirror.

Concave mirror

Convex mirror

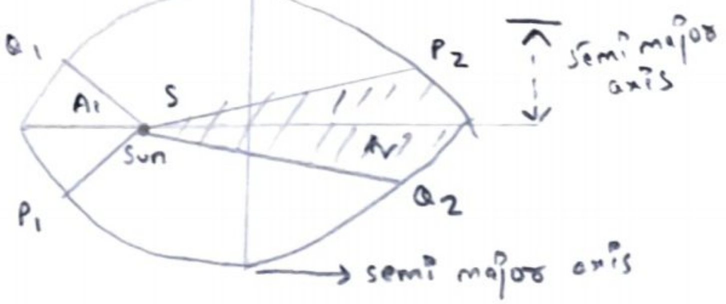
Kapler's Law of Planetary Motion

i) **Laws of Elliptical Orbit** :

A planet moves around the sun in an elliptical orbit with sun situated at one of its foci.

ii) **Laws of areal velocities** :

A planet moves around the sun in such away that its areal velocity is constant i.e the line joining the planet with the sun sweeps equal areas in equal interval of time.



Let 't' be the time taken by the planet to go from P_1 to Q_1. so that the line SP_1 traverses an area P_1SQ_1 while going from P_2 to Q_2, the planet moves is such a way that Area P_2SQ_2 = Area P_1SQ

Since $SP_2 > SP_1$

$\therefore P_2Q_2 < P_1Q_1$

P_1Q_1 and P_2Q_2 are the distances travelled, along the orbit in same time.

$\therefore$ we conclude that the orbital velocity of a planet is a uniform. It is largest when the planet is nearest to sun and its least when the planet is maximum distance away from the sun.

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Scalars and Vectors

Physical quantity is a quantity which can be measured.
e.g. length, mass, force. P.Q. → numerical value (magnitude) → unit
Types: Fundamental, Derived

Fundamental: L, M, T, I, A, 7, cd, mole — cannot be expressed in terms of any other phy. quantity.

Scalars – quantity which does not have direction; only magnitude. e.g. work, speed

Vectors – ~~only dirⁿ~~ both magnitude & dirⁿ.
e.g. force = 5N east, velocity = 5m/s west, displacement = 10m north
A = 4 units |A| = 4 units → magnitude $\vec{A}$ = 4 units south } vector
A = 4 " "

Representation ⊖ head → tail

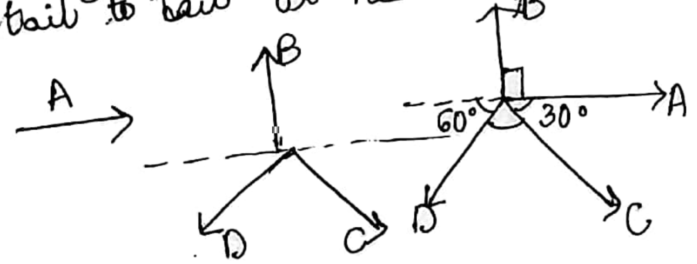
Types of vectors

1. Equal vectors – magnitude same, dirⁿ same.
   v_1 = 5m/s east, v_2 = 5m/s south.
2. Unequal vectors – either magnitude or dirⁿ not same. 5m/s east, 5m/s south
3. Parallel vectors – dirⁿ same. $\theta = 0°$
4. Antiparallel vectors – opposite dirⁿ. $\theta = 180°$
5. Collinear vectors – vectors which lie on the same line
6. Coplanar " – which lie on the same plane.
   Any 2 vectors are always coplanar.
7. Concurrent vectors – acting at same point F_1, F_2, F_3
8. Zero vector – Its dirⁿ is arbitrary (any dirⁿ)
9. Unit vector – value = 1. magnitude = 1. $\hat{A}$.

Angle b/w 2 vectors

tail to tail or head to head

$0 \leq \theta \leq 180°$ smaller



Vector Addition

$\sin = \frac{p}{h}$ $\tan = \frac{p}{b}$

$\cos = \frac{b}{h}$

	0°	30°	45°	60°	90°
sin	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1
cos	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0
tan	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞

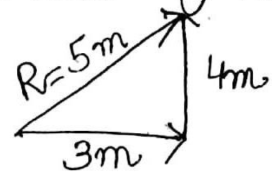
1) Head-tail
2) Parallelogram ~~method~~ law
3) Triangle law

1. Head-tail method

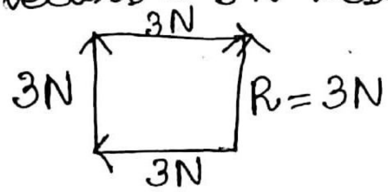
Join tail of next vector with head of previous vector.

$\vec{A} + \vec{B} = \vec{R}$ Join tail of 1st vector with head of last vector.

Q) 3m east + 4 m north = R.

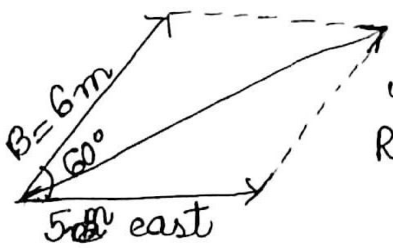


Q) 3 vectors - 3 N West, 3 N North, 3N East. $R = \vec{A} + \vec{B} + \vec{C}$



2. Parallelogram Law:
Join two vectors from tail to tail as two adjacent sides of a parallelogram. Complete imaginary ||gm.

$\vec{A} = 5$ east, $\vec{B} = 6$ 60° from east. R = diagonal of ||gm from common point.



$\vec{R} = \vec{A} + \vec{B}$ $\boxed{R^2 = A^2 + B^2 + 2AB\cos\theta}$

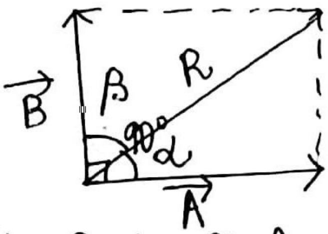
where θ = angle b/w 2 vectors.

$R^2 = 5^2 + 6^2 + 2 \times 5 \times 6 \times \cos 60^\circ$

$= 25 + 36 + 60 \times \frac{1}{2}$

Q) Add two vectors 6 units, 8 units at 90°.

$\vec{A} = 6$
$\vec{B} = 8$
$\theta = 90^\circ$



$R^2 = A^2 + B^2 + 2AB\cos\theta$

$= 6^2 + 8^2 + 2 \times 6 \times 8 \times \cos 90^\circ$

$= 36 + 64 = 100$

$R = 10$ (magnitude) $\rightarrow$ dir^n of R

R → vector
→ magnitude
→ dir^n

R dir^n from vector A (α) $\boxed{\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}}$

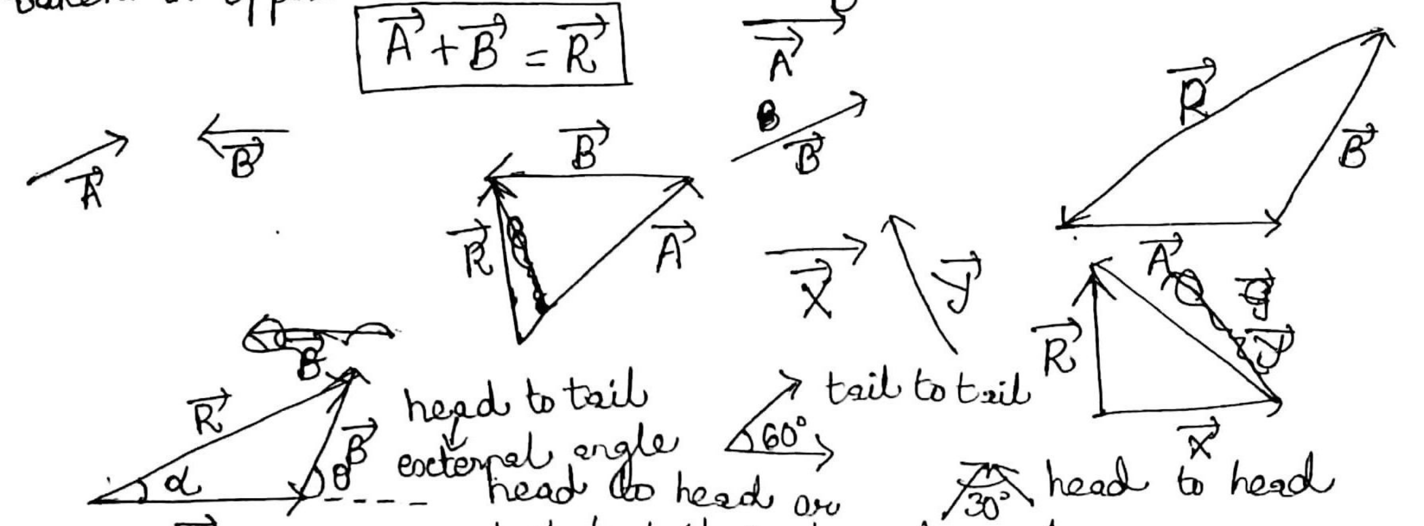
$\boxed{\tan\beta = \frac{A\sin\theta}{B + A\cos\theta}}$

$|R|^2 = A^2 + B^2 + 2AB\cos\theta$

Triangle law of vector addition.

If two vectors are represented by two sides of a Δ taken in order then the resultant is given by the third side of the Δ taken in opposite order.

$$\boxed{\vec{A}+\vec{B}=\vec{R}}$$

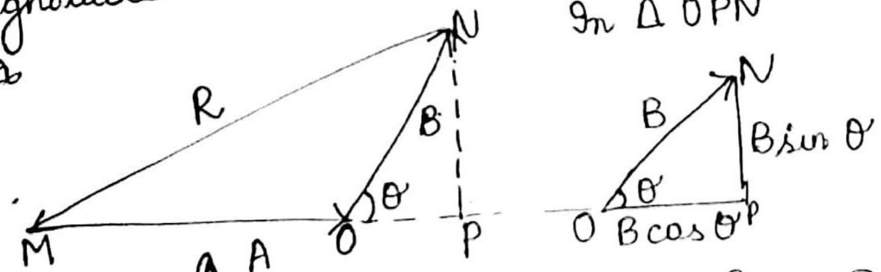


$$\boxed{R^2 = A^2+B^2+2AB\cos\theta}$$

↓ magnitude

$$\boxed{\tan\alpha = \frac{B\sin\theta}{A+B\cos\theta}}$$

In Δ OPN



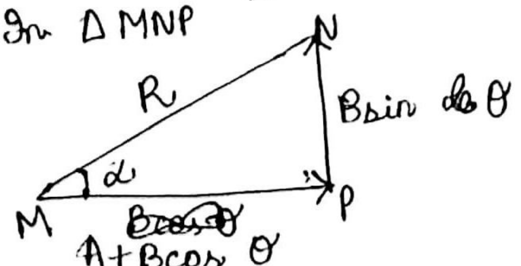
$\sin\theta = \frac{p}{h} = \frac{NP}{ON} = \frac{NP}{B}$

$\Rightarrow NP = B\sin\theta$

$\cos\theta = \frac{b}{h} = \frac{OP}{ON} = \frac{OP}{B}$

$\Rightarrow OP = B\cos\theta$.

In Δ MNP



$MN^2 = NP^2 + MP^2$ (Pygathorous theorem)

$R^2 = (B\sin\theta)^2 + (A+B\cos\theta)^2$

$R^2 = B^2\sin^2\theta + A^2 + B^2\cos^2\theta + 2AB\cos\theta$

$= A^2 + B^2(\sin^2\theta+\cos^2\theta) + 2AB\cos\theta$

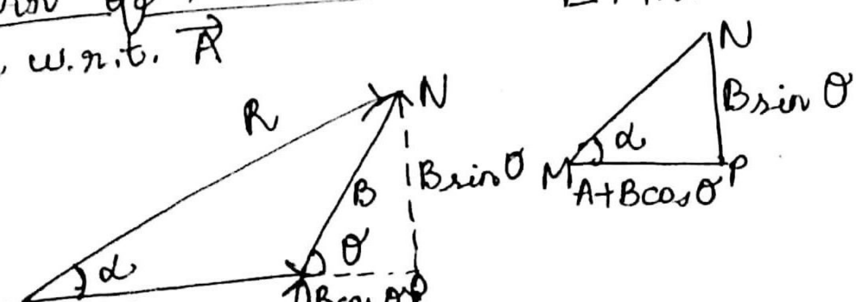
$$\boxed{R^2 = A^2+B^2+2AB\cos\theta}$$

A, B, R cannot be -ve.

Dir^n of resultant

α w.r.t. $\vec{A}$

Δ MNP



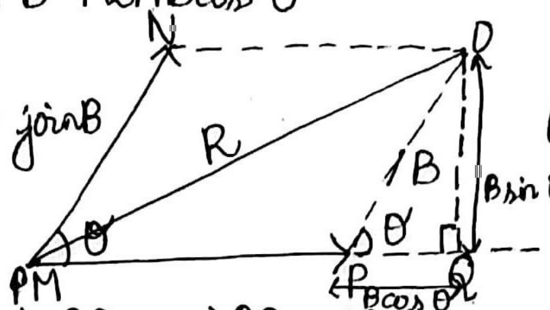
$\tan\alpha = \frac{p}{b} = \frac{NP}{MP}$

$\tan\alpha = \frac{B\sin\theta}{A+B\cos\theta}$.

Derive: $R^2 = A^2 + B^2 + 2AB\cos\theta$

$\vec{A}, \vec{B}, \vec{\theta}, \vec{R}$

$\theta \to$ tail to tail join B



11gm - pair of opposite sides are ∥ & equal

$\angle OPQ = \theta$ (corresponding ∠s)

ΔPOQ $\quad \cos\theta = \frac{b}{h} = \frac{PQ}{OP} \Rightarrow PQ = OP\cos\theta = B\cos\theta$

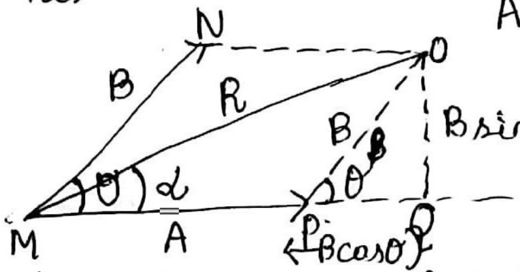
$\sin\theta = \frac{P}{h} = \frac{OQ}{OP} \Rightarrow OQ = OP\sin\theta = B\sin\theta$

ΔOQM $\quad (MO)^2 = (OQ)^2 + (MQ)^2 \Rightarrow R^2 = (B\sin\theta)^2 + (A + B\cos\theta)^2$

$\Rightarrow R^2 = B^2\sin^2\theta + A^2 + B^2\cos^2\theta + 2AB\cos\theta \cancel{= B^2(\sin^2\theta + \cos^2\theta)}$

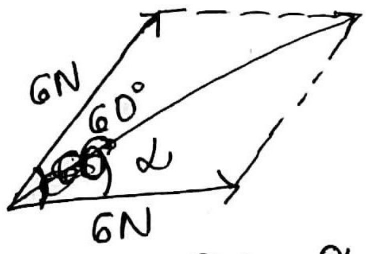
$\Rightarrow R^2 = B^2(\sin^2\theta + \cos^2\theta) + A^2 + 2AB\cos\theta = B^2 + A^2 + 2AB\cos\theta$

Dir^n of resultant : $\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}$



ΔOQM $\quad \tan\alpha = \frac{OQ}{MQ} = \frac{B\sin\theta}{A + B\cos\theta}$

Q) Two forces of magnitude 6N each act at a pt. as shown. Find the resultant. (a) $6\sqrt{3}$, 30° (b) $3\sqrt{3}$, 30° (c) $2\sqrt{3}$, 45° (d) 6, 45°.



$R^2 = A^2 + B^2 + 2AB\cos\theta$

$= 6^2 + 6^2 + 2 \times 6 \times 6\cos 60°$

$= \cancel{36 + 36 + 72 \times \frac{1}{2} = 108}$ $\quad 6^2 + 6^2 + 6^2 \times \frac{1}{2} \times 2$

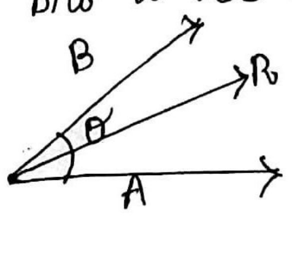
$R^2 = 3 \times 6^2 \Rightarrow R = 6 \times \sqrt{3}$

$\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta} = \frac{6\sin 60°}{6 + 6\cos 60°} = \frac{6 \times \frac{\sqrt{3}}{2}}{6 + 6 \times \frac{1}{2}} = \frac{3\sqrt{3}}{9} = \frac{1}{\sqrt{3}}$

$\alpha = \tan^{-1}\frac{1}{\sqrt{3}} = 30°$.

Q) ~~Two~~ 2 vectors of equal magnitude are added to give resultant which is of same magnitude as the two resultants. Find the angle b/w 2 vectors.

$R = A = B$.



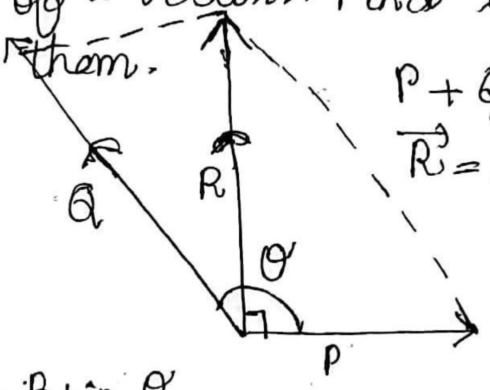
$R^2 = A^2 + B^2 + 2AB\cos\theta$

$x^2 = x^2 + x^2 + 2x \times x\cos\theta = 2x^2 + 2x^2\cos\theta = \cancel{2x^2(1+\cos\theta)}$

$\Rightarrow -x^2 = 2x^2\cos\theta \Rightarrow \cos\theta = \frac{-x^2}{2x^2} = -\frac{1}{2} \Rightarrow \theta = \cos^{-1}\left(-\frac{1}{2}\right) = 120^\circ$

$x \neq 0$

Q) 2 vectors P & Q has a sum of 18 & their resultant is 12. The resultant is ⊥ to smaller of 2 vectors. Find the value of P & Q and angle b/w them.



$P + Q = 18$

$\vec{R} = 12$

Sol^n: $P + Q = 18$ $\quad \vec{P} + \vec{Q} = 12$

Let P be smaller vector.

$R \perp P$. $\quad \alpha = 90^\circ$

$R^2 = P^2 + Q^2 + 2PQ\cos\theta$ $\quad \alpha = 90^\circ$

$12^2 = P^2 + Q^2 + 2PQ\cos\theta$ — ① $\quad \tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}$

$\tan 90^\circ = \frac{Q\sin\theta}{P + Q\cos\theta}$ $\cancel{\Rightarrow Q\sin\theta = P + Q\cos\theta}$

$\Rightarrow \infty = \frac{1}{0}$ ②

$P + Q\cos\theta = 0$

$Q\cos\theta = -P$

$12^2 = P^2 + Q^2 - 2P^2 = Q^2 - P^2$

$\Rightarrow (Q+P)(Q-P) = 144$

$\Rightarrow 18 \times (Q-P) = 144 \Rightarrow Q - P = 8$

$Q + P = 18$

$Q - P = 8$

$2Q = 26 \Rightarrow Q = 13$

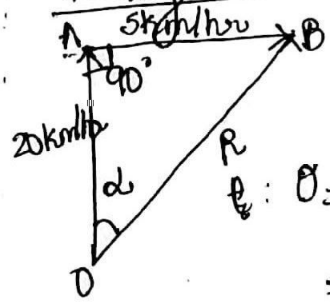
$P = 18 - Q = 18 - 13 = 5$

$Q\cos\theta = -P$

$13\cos\theta = -5$

$\Rightarrow \cos\theta = -\frac{5}{13}$

Triangle law



$R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$

$= \sqrt{20^2 + 5^2 + 2 \times 20 \times 5 \times \cos 90^\circ}$

$= \sqrt{400 + 25 + 0} = \sqrt{425} = 20.61$ km/hr.

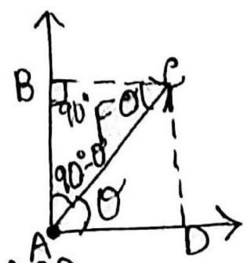
$\theta = \tan^{-1}\left(\frac{Q\sin\theta}{P + Q\cos\theta}\right) = \tan^{-1}\frac{5\sin 90^\circ}{20 + 5\cos 90^\circ}$

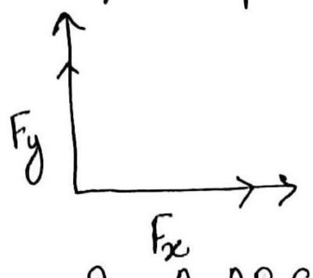
$= \tan^{-1}\left(\frac{5}{20}\right) = \tan^{-1}(0.25)$

Resolution of vectors

$F \to 2$ compones - x dir^n & y dir^n.

$\vec{F} = \vec{F_x} + \vec{F_y}$





$F_x = F\cos\theta$

$F_y = F\sin\theta$

In ACD

$\cos\theta = \frac{AD}{CA} = \frac{AD}{F}$

$\Rightarrow AD = F\cos\theta$

In Δ ABC

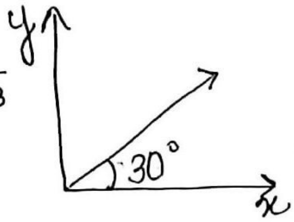
$\sin\theta = \frac{AB}{AC} = \frac{AB}{F}$

$\Rightarrow AB = F\sin\theta$

Q) $\vec{A} = 10$ ~~Ax~~ Find A_x, A_y.

$A_x = A\cos\theta = 10\cos 30° = \cancel{10}^{5} \times \frac{\sqrt{3}}{\cancel{2}} = 5\sqrt{3}$

$A_y = A\sin\theta = 10\sin 30° = \cancel{10}^{5} \times \frac{1}{\cancel{2}} = 5$



Q) Find $\sqrt{A_x^2 + A_y^2} = \sqrt{(5\sqrt{3})^2 + 5^2} = \sqrt{25\times 3 + 25} = \sqrt{75+25} = \sqrt{100} = 10$

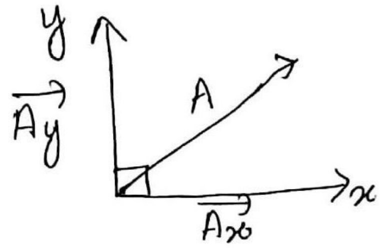
$$\boxed{|A| = \sqrt{A_x^2 + A_y^2}}$$

Prove that $|A| = \sqrt{A_x^2 + A_y^2}$

$\vec{A} = \vec{A_x} + \vec{A_y}$

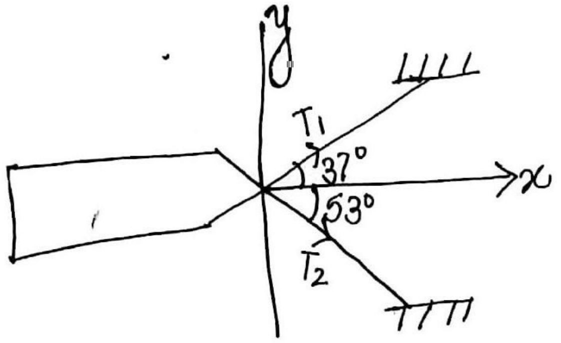
$A^2 = A_x^2 + A_y^2 + 2A_xA_y\cos 90° = A^2 = A_x^2 + A_y^2$

$|A| = \sqrt{A_x^2 + A_y^2}$



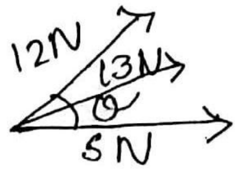
R.H.S. $\sqrt{A_x^2 + A_y^2} = \sqrt{A^2\cos^2\theta + A^2\sin^2\theta} = \sqrt{A^2} = A$.

$T_1 = 5$, $T_2 = 10$. Find component of T_1 & T_2 along x and y.



Q.

Q) If the resultant of 2 forces 5N & 12N is 13N. What is the angle b/w them.



$F = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta}$

$\Rightarrow 13 = \sqrt{5^2 + 12^2 + 2\times5\times12\times\cos\theta}$

$\Rightarrow 13 = \sqrt{25+144+120\times\cos\theta} \Rightarrow 13^2 = 25+144+120\cos\theta$

$\Rightarrow 169 - 169 = 120\cos\theta \Rightarrow 120\cos\theta = 0 \Rightarrow \cos\theta = 0 \Rightarrow \theta = 90^\circ$.

Properties of vector addition

1. Commutative $\vec{A}+\vec{B} = \vec{B}+\vec{A}$.
2. Distributive $m(\vec{A}+\vec{B}) = m\vec{A}+m\vec{B}$.
3. Associative $(\vec{A}+\vec{B})+\vec{C} = A+(\vec{B}+\vec{C})$.
4. Vector addition of a vector with its -ve vector gives a null vector.

$$\vec{A}+(-\vec{A}) = \vec{0}.$$

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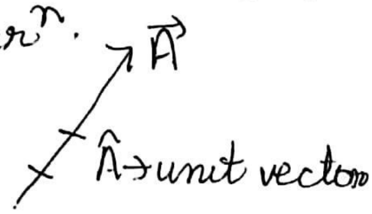
Vector Multiplication

<u>Unit Vector</u>: A unit vector is a dimensionless vector having a magnitude of exactly 1 & it gives dir^n.



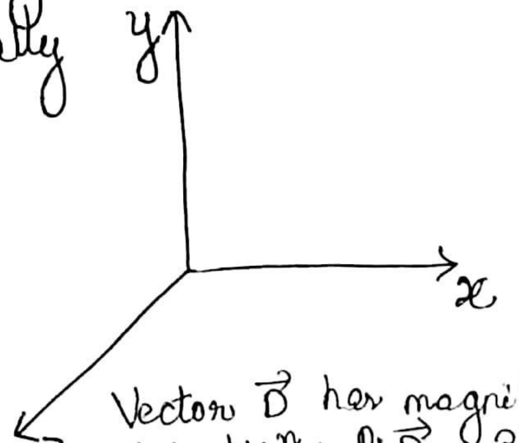
$\vec{A}$ = magnitude of A $\times$ dir^n of A.

$= |A| \times \hat{A}$

$$\boxed{\hat{A} = \frac{\vec{A}}{|A|}}$$

Orthogonal unit vectors: $\hat{i}, \hat{j}, \hat{k}$

mutually $\perp^{ar}$



$\hat{i} \rightarrow$ unit vector in x - dir^n

$\hat{j} \rightarrow$ " " " y "

$k \rightarrow$ " " " z "

Vector $\vec{A}$ has magnitude 5 units and is in the dir^n of x-axis.

$\vec{A} = |A|\hat{A} = 5\hat{i}$

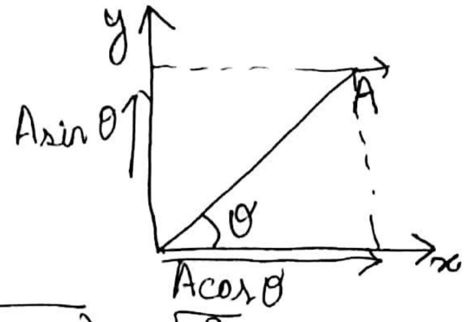
Vector $\vec{D}$ has magnitude 3 units in $+x$ dir^n & $+4$ units in $+y$ dir^n & $\vec{D} = 3\hat{i} + 4\hat{j}$.

Find: i) $A_x = A\cos\theta$ ii) $A_y = A\sin\theta$

iii) $\vec{A_x} = |A_x|\hat{A_x} = \cancel{A\cos\theta}\ A\cos\theta\,\hat{i}$

iv) $\vec{A_y} = |A_y|\,\hat{A_y} = A\sin\theta\,\hat{j}$

v) $\vec{A} = \vec{A} = A\cos\theta\,\hat{i} + A\sin\theta\,\hat{j} = \vec{A_x} + \vec{A_y}$



vi) $|A| = A$

vii) $\sqrt{A_x^2 + A_y^2} = \sqrt{(A\cos\theta)^2 + (A\sin\theta)^2} = \sqrt{A^2(\cos^2\theta + \sin^2\theta)} = \sqrt{A^2} = A$.

viii) $\tan\theta = \frac{A_y}{A_x} = \cancel{\frac{A\sin\theta}{A\cos\theta}} =$

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

$|A| = \sqrt{(A_x)^2 + (A_y)^2}$

Q) $\vec{B} = 5\hat{i} - 12\hat{j}$ $|B| = \sqrt{5^2 + (-12)^2} = \sqrt{25 + 144} = \sqrt{169} = 13$.

Vector Multiplication

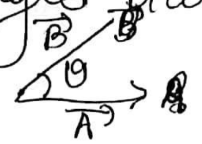
Product of two vectors is of 2 types:-

a) Scalar product or dot product

b) Vector ,, ,, cross ,,

a) **Scalar Product of 2 vectors**: The scalar product of 2 vectors is defined to be the product of their magnitudes and cosine of the smaller angle b/w them.

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



Properties of dot product:

i) commutative. $\vec{A}\cdot\vec{B} = \vec{B}\cdot\vec{A}$

ii) distributive $\vec{A}\cdot(\vec{B}+\vec{C}) = \vec{A}\cdot\vec{B} + \vec{A}\cdot\vec{C}$

iii) associative $(m\vec{a})\cdot(n\vec{B}) = mn(\vec{a}\cdot\vec{B}) = (n\vec{a})\cdot(n\vec{B})$

iv) Dot product of 2 mutually $\perp^{ar}$ vectors is zero.

$\vec{A}\cdot\vec{B} = AB\cos 90^\circ = 0$

v) Dot product of 2 parallel vectors is equal to the product of their magnitudes. $\vec{A}\cdot\vec{B} = AB\cos 0 = AB$.

vi) Dot product of 2 antiparallel vectors is equal to the -ve of the product of their magnitudes.

$\vec{A}\cdot\vec{B} = AB\cos 180^\circ = -AB$

vii) Dot product of two equal vectors is equal to square of the magnitude of the vector.

$\vec{A}\cdot\vec{A} = A^2 \qquad \hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$

Dot product in terms of components of vectors.

Let $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$, $\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$

$\vec{A}\cdot\vec{B} = (A_x\hat{i} + A_y\hat{j} + A_z\hat{k})\cdot(B_x\hat{i} + B_y\hat{j} + B_z\hat{k})$

$= A_xB_x\,\hat{i}\cdot\hat{i} + A_xB_y\,\hat{i}\cdot\hat{j} + A_xB_z\,\hat{i}\cdot\hat{k} + A_yB_x\,\hat{j}\cdot\hat{i} + A_yB_y\,\hat{j}\cdot\hat{j} + A_yB_z\,\hat{j}\cdot\hat{k} + A_zB_x\,\hat{k}\cdot\hat{i} + A_zB_y\,\hat{k}\cdot\hat{j} + A_zB_z\,\hat{k}\cdot\hat{k}$,

$\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y + A_zB_z$.

$$\cos\theta = \frac{\vec{A}\cdot\vec{B}}{AB}$$

2. Vector product

Vector product of 2 vectors $\vec{A}$ and $\vec{B}$ is a new vector $\hat{n}$ whose magnitude is given by the product of the magnitudes of the vectors and sine of the smaller angle between them & which is $\perp^{ar}$ to the plane containing the two vectors.

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

$$0 \leq \theta \leq 180°.$$

$\vec{n}$ is $\perp^{ar}$ to $\vec{A}$ as well as $\vec{B}$ & also to the plane containing $\vec{A}$ & $\vec{B}$.

Properties of vector product

i) not commutative $\vec{A} \times \vec{B} \neq \vec{B} \times \vec{A}$. $\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$.

ii) associative $m\vec{A} \times \vec{B} = \vec{A} \times m\vec{B} = m(\vec{A} \times \vec{B})$.

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

iv) Vector product of collinear vectors is zero.

a) Parallel vectors $\theta = 0°$ $\vec{A} \times \vec{B} = AB \sin\theta \, \hat{n} = \vec{0}$ = null vector.

b) Antiparallel vectors $\theta = \pi$ $\vec{A} \times \vec{B} = AB \sin 180° \, \hat{n} = \vec{0}$ = null vector

v) Vector product of equal vectors is zero.

$$\vec{A} \times \vec{A} = \vec{0}$$

$$\hat{i} \times \hat{i} = \hat{j} \times \hat{j} = \hat{k} \times \hat{k} = 0.$$

vi) Magnitude of vector product of 2 mutually $\perp^{ar}$ vectors is equal to the product of their magnitudes

$$|\vec{A} \times \vec{B}| = AB \sin 90° = AB.$$

$$\Rightarrow \hat{i} \times \hat{j} = \hat{k}, \quad \hat{j} \times \hat{k} = \hat{i}, \quad \hat{k} \times \hat{i} = \hat{j}$$

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

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

$$\sin\theta = \frac{|\vec{A} \times \vec{B}|}{AB}$$

Unit-10 – CURRENT ELECTRICITY

Electric current:

The flow of charge in a definite direction constitutes the electric current and the time rate of flow of charge through any cross-section of a conductor is the measure of current i.e

$$\text{Electric current}(I) = \frac{\text{total charge flowing}}{\text{time taken}} = \frac{q}{t}$$

Unit of electric current:

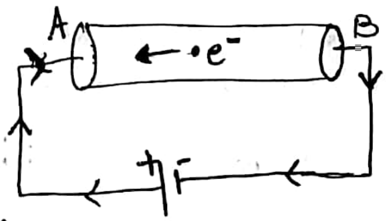
S.I unit of current is Ampere (A)

$$1 \text{ ampere}(A) = \frac{1 \text{ coulomb}(C)}{1 \text{ sec}} = 1\,C s^{-1}$$

The current through a wire is said to be 1 ampere, if one coulomb of charge is flowing per second through a section of the wire.

* Current is a scalar quantity, because for its addition the law of scalar addition are applicable and not the law of vector addition.

* The direction of flow of +ve charge gives the direction of current. This is called conventional current.



* The direction of flow of –ve charge i.e electrons gives the direction of electronic current.

The direction of electronic current is opposite to that of conventional current as shown in fig

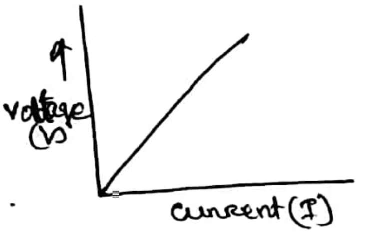
OHM'S LAW

Ohm's law states that the current (I) flowing through a Conductor is directly proportional to the potential difference (V) across the ends of the conductor, provided physical conditions of the conductor such as temperature, mechanical strain etc are kept constant. i.e

$I \propto V$ or $V \propto I$

$\Rightarrow V = IR$

$\Rightarrow \frac{V}{I} = R =$ a constant.



'R' is known as the resistance of the conductor. It depends upon the length, shape and nature of the material of the conductor.

Applications of Ohm's law :-

1. It is widely used in Circuit analysis.
2. It is used in ammeter, multimeter etc
3. It is used to design resistors.
4. It is used to get the desired circuit drop in circuit design.
5. Advanced laws such as Kirchoff's law, Thevenin's law are based on Ohm's law.
6. Electric heater, kettles and other types of equipment working principle ~~follows~~ follows the Ohm's law.
7. Laptop and mobile charger using DC power supply in operation and working principle of DC power supply depends on Ohm's law.

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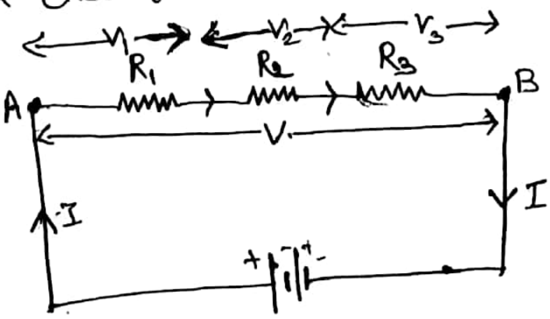
Resistors in Series Connection

A circuit is said to be connected in series, when the same amount of current flows through the resistors. In such circuits, the voltage across each resistor is different.

In series connection, if any resistor is broken or a fault occurs, then the entire circuit is turned off. The construction of a series circuit is simpler compared to parallel circuit.



For the above circuit the total resistance is given as

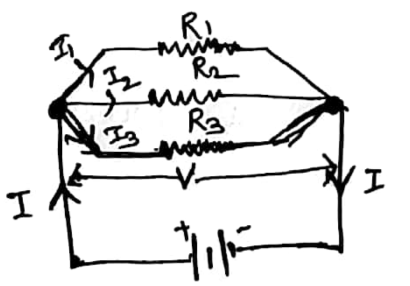
$$\boxed{R_{total} = R_1 + R_2 + \cdots + R_n}$$

∴ Total resistance of the system is equal to the sum of the individual resistance.

Resistors in parallel connection :-

A circuit is said to be connected in parallel when the voltage is same across the resistors. In such circuits, the current is branched out and recombines when branches meet at a common point.

A resistor or any other component can be connected or disconnected easily without affecting other elements in parallel circuit.



∴ Total resistance in parallel combination is

$$\boxed{\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}}$$

The sum of reciprocal of resistance of an individual resistor is the total reciprocal resistance of the system.

KIRCHHOFF'S LAW

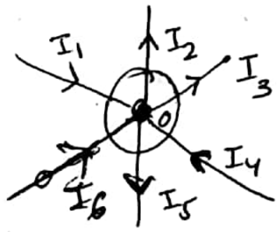
In 1845, a German Physicist, Gustav Kirchhoff developed a pair of laws, that deals with conservation of current and energy within electric circuits. These two laws are commonly known as Kirchhoff's voltage and current law. These laws helps in calculating the electrical resistance of a complex network or impedance in case of AC and the current flow in different streams of the network.

Kirchhoff's first law or Kirchhoff's Junction law or Kirchhoff's Current law :-

It states that the algebraic sum of currents meeting at a junction in a closed circuit is zero ie $\Sigma I = 0$

Or

It states that the total current entering a junction or a node is equal to the charge leaving the node as no charge is lost.



Consider a junction 'O' in the electrical circuit at which 6 conductors are meeting.

Let I_1, I_2, I_3, I_4, I_5 and I_6 be the current in these conductors in directions as shown in fig.

According to sign convention rule, the current flowing in a conductor towards the junction is taken as positive and the current flowing away from the junction is taken as -ve

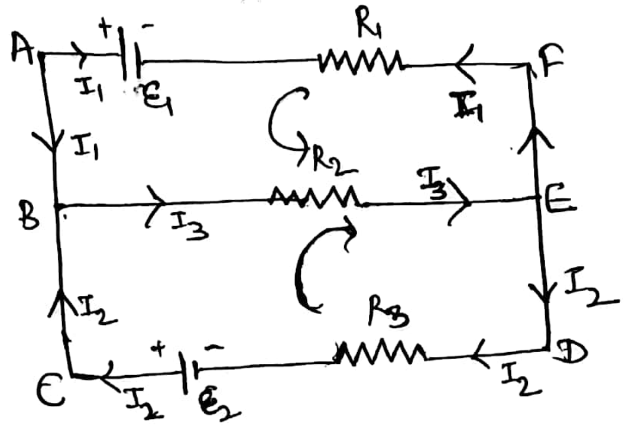
According to Kirchhoff's first law at junction 'O'

$$(I_1) + (-I_2) + (-I_3) + (I_4) + (-I_5) + (I_6) = 0$$

$$\Rightarrow I_1 - I_2 - I_3 + I_4 - I_5 + I_6 = 0 \quad \text{or} \quad \boxed{\Sigma I = 0}$$

Kirchhoff's Second Law or Kirchhoff's Loop law or Kirchhoff's Voltage law

It states that the algebric sum of changes in potential around any closed path of electric circuit or closed loop involving resistors and cells in the loop is zero i.e $\Sigma \Delta V = 0$



Consider a closed electrical circuit as shown in above fig., containing two cells of e.m.f $\mathcal{E}_1$ and $\mathcal{E}_2$ and three resistors of resistance R_1, R_2 and R_3.

~~According to~~ Follow the sign convention rule, traversed a closed path of a circuit in clockwise or anticlockwise direction.

(i) The e.m.f of a cell is taken -ve if one moves in the direction of increasing potential (i.e from -ve pole to +ve pole) through the cell and is taken +ve if one moves in the direction of decreasing potential (i.e from +ve pole to -ve pole) through the cell. ~~mean~~

(ii) The product of resistance and current in an arm of the circuit is taken +ve, if the direction of current in that arm is in the same sense as one moves in a closed path and is taken -ve, if the direction of current in that arm is opposite to the sense as one moves in a closed path.

Let us applay Kirchhoff's 2nd law to the closed path ABEFA, we have

$$I_3R_2 + I_1R_1 - \mathcal{E}_1 = 0$$

$$\text{or } \mathcal{E}_1 = I_1R_1 + I_3R_2$$

Similarly for closed path ABCDEFA, we have

$$\mathcal{E}_2 - I_2R_3 + I_1R_1 - \mathcal{E}_1 = 0$$

$$\mathcal{E}_1 - \mathcal{E}_2 = I_1R_1 - I_2R_3$$

$$\boxed{\Sigma \mathcal{E} = \Sigma IR}$$

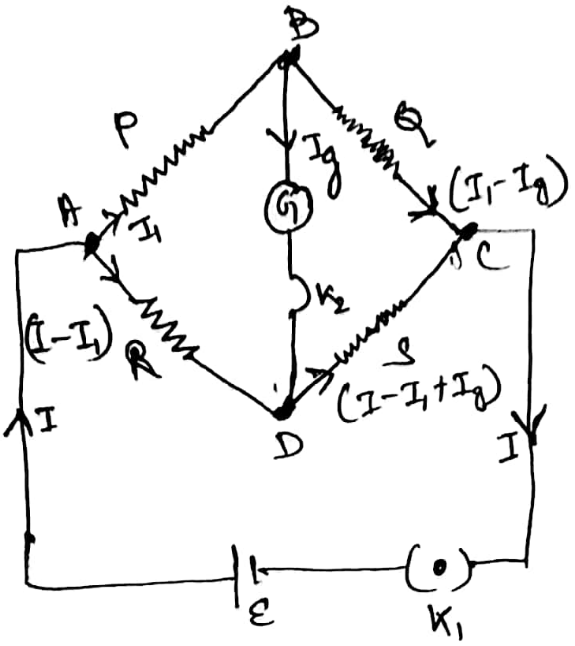
Difference b/w Kirchhoff's 1st and 2nd law

First law	Second law
1- This law supports the law of conservation of charge.	1- This law supports the law of conservation of energy.
2- According to this law $\Sigma I = 0$	2- According to this law $\Sigma \mathcal{E} = \Sigma IR$
3. This law can be used in open and closed circuits.	3. This law can be used in closed circuit.

WHEATSTONE BRIDGE

Wheatstone bridge is also known as a resistance bridge, calculate the unknown resistance by balancing the two arms of the bridge circuit. The wheatstone bridge circuit comprises two known resistors, one unknown resistors and one variable resistors connected in the form of a bridge.

* Wheatstone bridge principle states that, if four resistance P, Q, R and S are arranged to form a bridge as shown in fig with cell E and one way a key K_1 between the points A and C and a galvanometer G and tapping key K_2 between the points B and D, on closing K_1 first and K_2 later, on, if galvanometer shows no deflection then bridge is balanced. In that case $\dfrac{P}{Q} = \dfrac{R}{S}$



* Wheatstone bridge works on the principle of null deflection... i.e the ratio of their resistance are equal and no current flows through the circuit.
* Under normal conditions, the bridge is in the unbalanced condition, where the current flows through the galvanometer.
* The bridge is said to be in a balanced condition, when no current flows through the galvanometer. This condition can be achieved by adjusting the known resistance and variable resistance.

Electrostatics

Electrostatics is the study of stationary electric charges. A rod of plastic rubbed with fur or a rod of glass rubbed with silk will attract small pieces of paper and is said to be electrically charged. The charge on plastic rubbed with fur is defined as negative, and the charge on glass rubbed with silk is defined as positive.

Electric charge

Electrically ~~charged objects have several important~~ characteristics: Laws of electrostatics:

→ Like charges repel one another.
→ Unlike charges attract each other.
→ Charge is conserved.

Coulomb's law (Coulomb's inverse-square law):

It is an experimental law of physics that quantifies the amount of force between two stationery, electrically charged particles. The electric force between charged bodies at rest is called electrostatic force or Coulomb force.

Statement of Coulomb's law: It states that the magnitude of the electrostatic force of attraction or repulsion between two point charges is directly proportional to the product of the magnitudes of charges and inversely proportional to the square of the distance between them.

$$|F| = \frac{k|q_1 q_2|}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$\varepsilon_0 \rightarrow$ permittivity of free space $\approx 8.854 \times 10^{-12}$

where k is the Coulomb's constant ($9 \times 10^{9}\ N.m^2 C^{-2}$), q_1 and q_2 are the magnitudes of the charges and r is the distance between the charges.

The force is along the straight line joining the two charges.

Units and dimensions of K

$$F = \frac{Kq_1q_2}{r^2} \Rightarrow K = \frac{Fr^2}{q_1q_2}$$

Units of $K = \frac{Nm^2}{C^2} = Nm^2C^{-2}$.

Dimensions of K : $\frac{[MLT^{-2}][L^2]}{[AT][AT]} = [ML^3T^{-4}A^{-2}]$

Units and dimensions of ε_0:

$$K = \frac{1}{4\pi\varepsilon_0} \Rightarrow \varepsilon_0 = \frac{1}{4\pi K} \qquad \varepsilon_0 = \frac{1}{K}$$

Units of $\varepsilon_0 = \frac{1}{Nm^2C^{-2}} = N^{-1}m^{-2}C^2$

Dimension of $\varepsilon_0 = \frac{1}{K} = \frac{1}{[ML^3T^{-4}A^{-2}]} = [M^{-1}L^{-3}T^4A^2]$

Limitations of Coulomb's law:

→ It can be applied only for static charges.
→ It applies only to point charges
→ Separation between charges should be very large.
→ Separation between charges should not be very small.

Permittivity:-

Permittivity is the property of a particular medium which affects the magnitude of the force existing between two point charges.

Greater the value of the permittivity of the medium placed between the two charged bodies, the lesser the value of force existing between them.

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Types of permittivity:

Every medium posses two types of permittivity.

1. Absolute permittivity (ε_0) 2. Relative permittivity (ε_r)

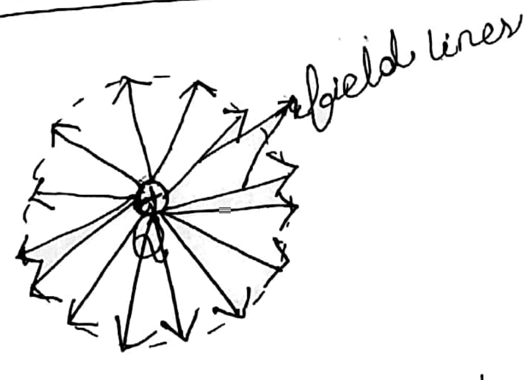
1. **Absolute permittivity** (ε_0) - The absolute permittivity of air or vaccum is minimum and its value is 8.854×10^{-12} F/m whereas the value of absolute or actual permittivity ε of all other insulating medium is more than ε_0.

2. **Relative permittivity** (ε_r) - The ratio of the absolute permittivity of the insulating medium to the absolute permittivity (ε_0) of the air or vaccum is known as relative permittivity.

Relation between relative & absolute permittivity

$$\boxed{\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}}$$

Electric ~~Potential~~ field



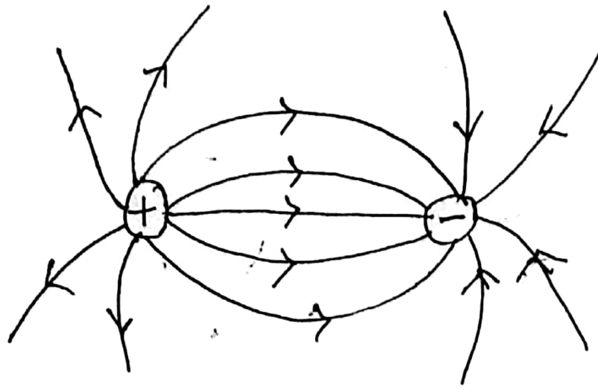
Electric field can be defined as the force per unit charge exerted ~~on~~ a positive test charge at rest at that point.

$$E = \frac{\vec{F}}{q}$$

An electric field is the physical field that surrounds electrically charged particles and excerts force on all other charged particles in the field, either attracting or repelling them.

Unit - N/C or NC^{-1}.

A force

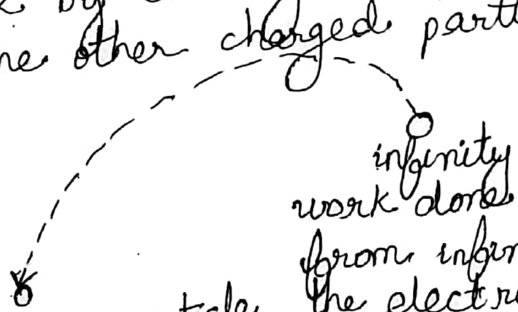


Electric field lines

Electric field line is an imaginary line or curve drawn through a region of empty space so that its tangent at any point is in the direction of the electric field vector at that point. The relative closeness of the lines at some place gives an idea about the intensity of electric field at that point. 1

Electric Potential:

Definition: The electric potential is defined as the capability of the charged body to do work. When the body is charged, either electrons are supplied to it, or they are removed from it. In both the cases, the work is done. This work is stored in the body in the form of electric potential. Thus, the body can do the work by exerting a force of attraction or repulsion on the other charged particles.



work done by moving a charge particle from infinity to other point is equal to the the electrical potential.

The capacity of the charged body to do work determines the electrical potential on it. The measure of the electrical potential is the work done to charge a body to 1 Coulomb.

Magnet and its Properties

A magnet is defined as an object which is capable of producing magnetic field.

Properties of magnet:

→ When a magnet is dipped in iron filings, we observe that the iron filings cling to the end of the magnet as the attraction is maximum at the ends of the magnet. These ends are known as poles of the magnet.

→ Magnetic poles always exist in pairs.

→ When a magnet is suspended freely in mid-air, it always points towards north-south direction. Pole pointing towards geographic north is known as North Pole and the pole pointing towards geographic south is known as the South Pole.

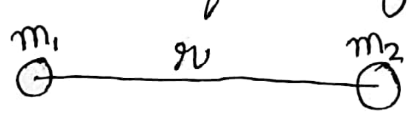
→ Like poles repel while unlike poles attract.

→ The magnetic force between the two magnets is greater when the distance between these magnets are lesser.

Coulomb's Law in Magnetism

When 2 magnets are kept near to each other, either there is a force of attraction or force of repulsion. This force can be evaluated by this law.

The force of attraction or repulsion between two magnetic poles is directly proportional to the product of the pole strength and inversely proportional to the square of the distance between them.



$$F \propto \frac{m_1 m_2}{r^2}$$

$$F = K\frac{m_1 m_2}{r^2}$$ k is a constant which depends upon material of the medium.

where $k = \frac{\mu}{4\pi}$ $\mu \rightarrow$ magnetic permeability of the medium.

$\mu = \mu_0 \mu_r$ μ_0 = permeability of free space.

$\mu_0 = 4\pi \times 10^{-7} H/m$ μ_r = relative permeability

If the two magnets are placed in air or free space, then

$$F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2} \quad (\mu_r = 1 \text{ for air})$$

$$F = 10^{-7} \frac{m_1 m_2}{r^2}$$

If ~~the~~ $r = 1m$, $m_1 = m_2 = 1$ unit pole, then

$$F = 10^{-7} \frac{1 \times 1}{1^2} = 10^{-7} N.$$

S.I. unit of ~~unit~~ pole strength = 1A·m

1Am is that pole which when placed in air or vaccum at a distance of 1m from an identical pole experiences a force of repulsion of 10^{-7} N.

Magnetic Field & Magnetic Field Intensity

The magnetic field is the area around the magnet in which the effect of magnetism is felt.

The strength of the magnetic field at a point is defined as the force experienced by a north pole of unit pole strength at that point.

Unit of ~~a~~ magnetic field → Tesla or N/Am.

$$\boxed{B = \frac{F}{m}}$$

B = magnetic field intensity

F = ~~fo~~ magnetic force m = pole strength

1 Tesla is defined as the magnetic field intensity that can generate ~~1~~ 1N of force per ampere of current per meter of the conductor.

Magnetic lines of force

Magnetic lines of force are the lines that depict the magnetic force that exists in the surrounding of the magnet.

Properties of magnetic lines of force

→ They emerge from the north pole and merge at the south pole.

→ As the distance between the poles increases, the density of magnetic lines decreases.

→ The direction of field lines inside the magnet is from South Pole to North Pole.

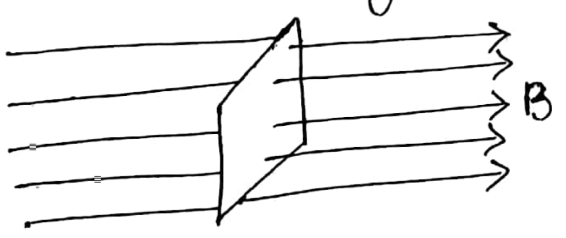
→ Magnetic lines do not intersect with each other.

→ The strength of the magnetic lines is the same throughout and is proportional to how close are the lines.

Magnetic Flux

The quantity of magnetic field linked to a surface area is known as magnetic flux.

$$\boxed{\phi_B = \vec{B}\cdot\vec{A}}$$



- It is denoted by 'ϕ_B'.
- It is a scalar quantity
- S.I. unit – weber (W)

Magnetic flux density (B)

It is defined as the no. of magnetic lines of flux that pass through a certain point on a space.

- B is a vector quantity
- S.I. unit = W/m^2 or Tesla

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

Dimensional formula for magnetic flux is $[ML^2T^{-2}A^{-1}]$