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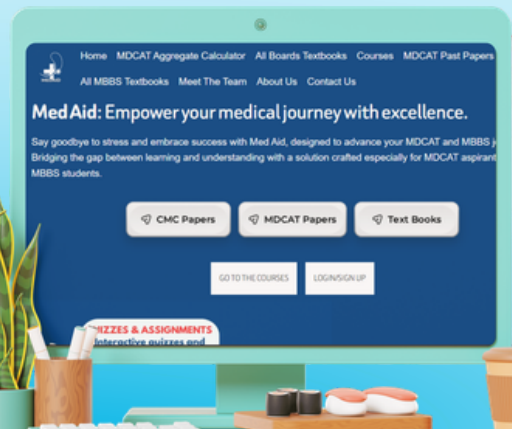
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- ▶ Comprehensive Course Revision
- ▶ Detailed Explanation of Topics
- ▶ Key Points, Tables, Flows Sheets & Diagrams
- ▶ Critical Concepts; Critical Thinking



A Kitab Dost Publication

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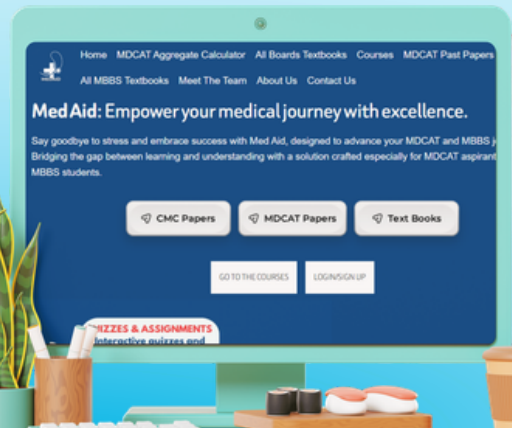
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COURSE CONTENT

- Displacement
- Velocity
- Displacement-time graph
- Acceleration
- Uniform acceleration
- Variable acceleration
- Graphical representation of acceleration with velocity time graph
- Newton's laws of motion (1st, 2nd, and 3rd law)
- Linear Momentum
- Law of conservation of momentum
- Collision
- Elastic collision
- Elastic collision in one dimension
- Elastic collision in one dimension under different cases
- Projectile motion
- Characteristics of projectile motion
- Time of flight
- Maximum height
- Horizontal range

DISPLACEMENT, VELOCITY

Rest and Motion

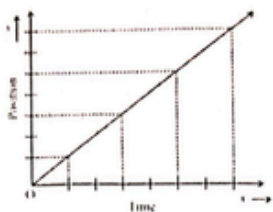
The concept of state of motion and rest are described relative to the observer.

- If a body does not change its state w.r.t surroundings, it is in the state of rest.
- If a body changes its state w.r.t surroundings, then it is in the state of motion.
- A moving body can possess both states of rest and motion, depending on the observer.

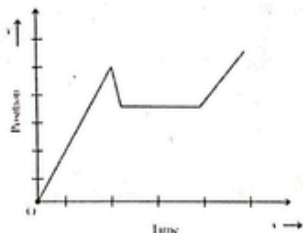
One dimensional	Two dimensional	Three dimensional
Motion of a body in a straight line is called one dimensional motion.	Motion of body in a plane is called two dimensional motion.	Motion of body in a space is called three dimensional motion.
When only one coordinate of the position of a body changes with time then it is said to be moving one dimensionally.	When two coordinates of the position of a body changes with time then it is said to be moving two dimensionally.	When all three coordinates of the position of a body changes with time then it is said to be moving three dimensionally.
<i>e.g.</i> Motion of car on a straight road. Motion of freely falling body.	<i>e.g.</i> Motion of car on a circular turn. Motion of billiards ball.	<i>e.g.</i> Motion of flying kite. Motion of flying insect.

Uniform Motion:

If an object is moving along the straight line covers equal distances in equal interval of time, then the motion is known as uniform motion.

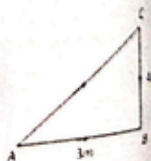
**Non-Uniform Motion:**

If an object covers unequal distances in equal interval or equal distance in unequal time interval, then it is known as non-uniform motion.

**Distance:**

The length of the actual path between initial and terminal position of a particle in interval of time is called distance covered by the particle. Distance is also known as path length.

- i) Distance is a scalar quantity.
- ii) It never reduces with time.
- iii) The distance covered by the object can't be negative.
- iv) SI unit of distance is metre (m).
- v) The dimension of the distance is $[M^0L^1T^0]$
- (vi) If a particle starts from A and reach to C through point B as shown in the figure. Then distance travelled by particle
 $= AB + BC$
 $= 7 \text{ m}$



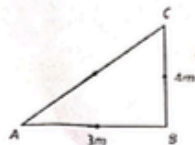
Displacement:

The shortest distance between the initial and final points of the body in a particular direction.

- Displacement is a vector quantity.
- Displacement of the object changes with time.
- Displacement of the object can be negative, positive or zero.
- SI unit of displacement is metre (m).
- The dimension of the distance is $[M \cdot L \cdot T^{-1}]$
- In the figure the displacement of the particle

$$\vec{AC} = \vec{AB} + \vec{BC}$$

$$|\vec{AC}| = \sqrt{3^2 + 4^2} = 5m$$



- The motion of a body along a circular path of circle point A to point B. In this case arc AB is a distance while chord AB is its displacement.

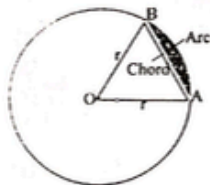
Example:

Compare distance and displacement of a body when its motion is along circular path from point A to B of a hemi sphere of radius 10 cm.

Solution: Distance = length along curved path of hemi sphere. *(half sphere)*

$$\text{Distance} = \frac{2\pi r}{2} = (3.14)(10) = 31.4\text{cm}$$

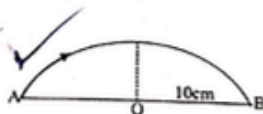
$$\begin{aligned} \text{Displacement} &= \text{Diameter of a hemi sphere} \\ &= 2r = 2 \times 10 = 20\text{cm} \end{aligned}$$

**Speed:**

Speed of an object is the ratio of distance travelled by the object to the time taken.

$$\text{Speed} = \frac{\text{Distance travelled}}{\text{Time taken}}$$

- Speed is a scalar quantity.
- SI unit of speed is m/s.
- The dimension of the speed is $[M \cdot L \cdot T^{-1}]$
- The speed of an object can't be negative.

**Uniform speed:**

An object is said to be moving with a uniform speed if it covers the equal distance in equal intervals of time.

Non-Uniform speed:

An object is said to be non-uniform speed if it covers the equal distance in the unequal time interval or unequal distance in the equal time interval.

Velocity:

Time rate of change of displacement is called velocity. It is a vector quantity and may be positive or negative.

$$\vec{v} = \frac{\text{Displacement}}{\text{Time}} = \frac{\Delta \vec{d}}{\Delta t}$$

$$\vec{v} = \frac{\vec{d}_2 - \vec{d}_1}{t_2 - t_1}$$

Uniform Velocity:

When a body covers equal displacements in equal interval of time, however small this time interval may be, then its velocity is said to be uniform.

Non-Uniform velocity:

An object is said to be non-uniform velocity if it covers equal distance in unequal time interval or unequal distance in an equal time interval.

Average velocity:

The ratio of total path length travelled divided by the total time interval during the motion is known as the average velocity of the object.

$$\frac{x_1 + x_2 + x_3 + \dots}{t_1 + t_2 + t_3 + \dots} = \frac{\sum_{i=1}^n x_i}{\sum_{i=1}^n t_i}$$

- When a body performs journey in two parts of **equal distance** with speed v_1 and v_2 then

$$\text{average speed } v_{av} = \frac{2v_1 v_2}{v_1 + v_2}$$

- When a body performs journey in two parts of **equal time** with speed v_1 and v_2 then

$$\text{average speed } v_{av} = \frac{v_1 + v_2}{2}$$

- When particle covers one-third distance at speed v_1 , next one third at speed v_2 and last one third at speed v_3 , then

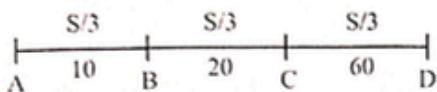
$$v_{av} = \frac{3v_1 v_2 v_3}{v_1 v_2 + v_2 v_3 + v_3 v_1}$$

- If a body travels with uniform velocity \vec{v}_1 for time t_1 and with uniform velocity \vec{v}_2 for time t_2 , then its **average velocity** will be

$$\vec{v} = \frac{\vec{s}_1 + \vec{s}_2}{t_1 + t_2} = \frac{\vec{v}_1 t_1 + \vec{v}_2 t_2}{t_1 + t_2}$$

Example:

A car traveled the first third of distance S at speed of 10 m s^{-1} , the second third at a speed of 20 m s^{-1} and last third at a speed of 60 m s^{-1} . Determine average speed of car.



$$v_{av} = \frac{\text{Total distance traveled}}{\text{total time}} = \frac{AB+BC+CD}{t_1+t_2+t_3}$$

$$= \frac{S/3+S/3+S/3}{\frac{S/3}{10} + \frac{S/3}{20} + \frac{S/3}{60}} = 18 \text{ m s}^{-1}$$

Instantaneous Velocity:

The instantaneous velocity \vec{v} of a body is defined as the limit of the ratio of change in position $\Delta \vec{d}$ (displacement) to the small-time interval Δt as Δt following an instant 't' approach zero:

$$\vec{v} = \lim_{\Delta t \rightarrow 0} \frac{\Delta \vec{d}}{\Delta t}$$

Relative Velocity:

The velocity of an object relative to some other object which might be stationary, moving slowly, moving with same velocity, moving with higher velocity or moving in opposite direction.

Example-1:

A motorcycle travelling on the highway at a velocity of 120 km/h *(in same direction)* passes a car travelling at a velocity of 90 km/h . From the point of view of a passenger on the car, what is the velocity of the motorcycle?

Solution:

Let us represent the velocity of the motorcycle as V_A and the velocity of the car as V_B . Now, the velocity of the motorcycle relative to the point of view of a passenger is given as

$V_{AB} = V_A - V_B$ Substituting the values in the above equation, we get

$$V_{AB} = 120 \text{ km/h} - 90 \text{ km/h} = 30 \text{ km/h}$$

Hence, the velocity of the motorcycle relative to the passenger of the car is 30 km/h .

Typical Speeds	
Motion	Speed m s^{-1}
Walking Ant	0.01
Human Swimming	2
Human Running	4
Flying Bee	5
Tortoise	9
100 Meters Dash	10
Running Cheetah	29
Falcon in a dive	37
Automobile	62
Jet Airline	267
Sound in Air	333
Moon around the earth	1023
Earth around the Sun	29600
Sun around galaxy	230000
Light (Electromagnetic Wave)	300000000

Example-2:

An aero-plane flies with a velocity of 450 m/s to the north, while another aero-plane B travels at a velocity of 500 m/s to the south. Calculate the relative velocity of the aero-plane A with respect to aero-plane B.

Solution:

The relative velocity of aeroplane A with respect to the velocity of aeroplane B is calculated as follows:

$$V_{AB} = V_A - V_B$$

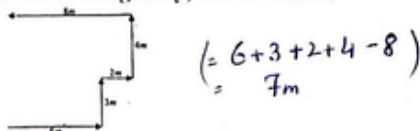
Substituting the values in the equation, we get

$$V_{AB} = 450 \text{ m/s} - (-500 \text{ m/s}) = 950 \text{ m/s}$$

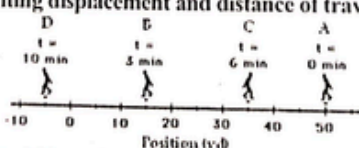
The velocity of aeroplane B is considered negative, as it flies in the opposite direction to that of aeroplane A.

CRITICAL THINKING

1. What is the displacement of the moving body, shown below?



- A. 6 m
 C. 8 m
 B. 7 m
 D. 23 m
2. A body moves from point P to point Q with a speed of 6ms^{-1} along a straight line then from Q to P with a speed of 4ms^{-1} . What is its average speed over the entire trip?
 A. 4ms^{-1}
 C. 5ms^{-1}
 B. 4.8ms^{-1}
 D. 5.5ms^{-1}
3. In the given diagram, the coach moves from position A to B to C to D. What is the coach's resulting displacement and distance of travel?







- A. 55yards left and 90 yards
 C. 55yards left and 95 yards
 B. 50yards left and 95 yards
 D. 45yards left and 95 yards

$$\begin{aligned} & \text{AB} + \text{BC} + \text{CD} \\ & 35 - 20 + 35 - 5 = 45 \quad \textcircled{1} \\ & 35 + 20 + 35 + 5 = 95 \quad \textcircled{2} \end{aligned}$$

DISPLACEMENT-TIME GRAPH

- The velocity at any instant is found by the slope of the displacement – time graph.
- For a body at rest, the displacement – time graph is a straight line parallel to the time axis.
- For a body moving with constant velocity, the displacement time graph is a straight line inclined to time axis.
- If slope increases, the body speeds up and if slope decreases, the body slows down.

Graph Shape	Slope	Velocity
	Constant positive	Velocity is constant
	positive	Velocity is increasing
	Constant (zero)	Velocity is zero
	positive	Velocity decreases

For your Information

- When the motion of a body is non-uniform then there is a curved line in displacement-time graph and the chord of this curved is represented the average velocity of the body as shown in fig a.
- In case of instantaneous velocity, the slope of the tangent at the point P of the curved line in displacement time graph shows instantaneous velocity of the body as shown in fig b.

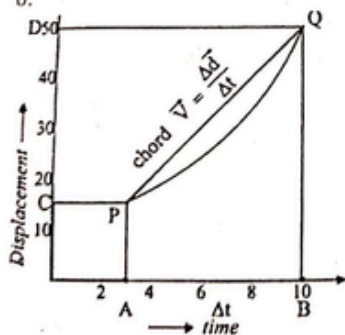


Fig. a

The chord in displacement-time graph shows average velocity of a moving body

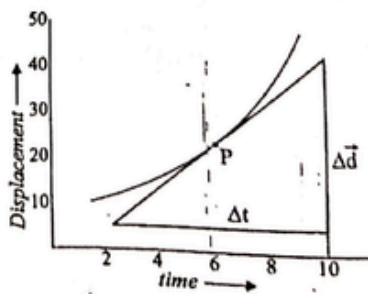


Fig. b

A point P in Displacement-time graph shows instantaneous velocity of a moving body

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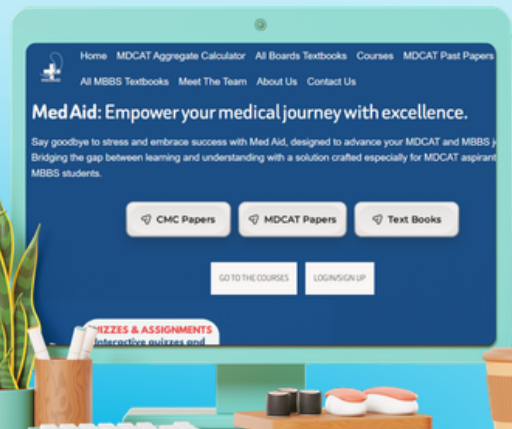
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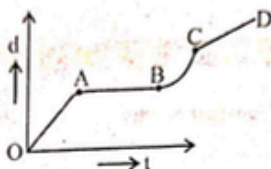
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CRITICAL THINKING ?

4. The displacement time graph for a particle moving in a straight line is shown below. The accelerations of the particle during the intervals OA, AB, BC and CD are



- A. 0, 0, +, 0
C. -, 0, -, -

- B. +, 0, -, +
D. -, 0, +, 0

ACCELERATION

Rate of change of velocity is known as acceleration. It is a vector quantity. If $\Delta \vec{v}$ is the change in velocity in time Δt , then acceleration is given as

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$

Acceleration may be positive or negative. Negative acceleration is termed as retardation. It indicates that the velocity of the body is decreasing with time.

Uniform Acceleration:

If the velocity of a body changes by same amount in same interval of time, then the acceleration of the body is known as uniform acceleration.

If a body travels with uniform acceleration a_1 for a time interval t_1 and with uniform acceleration a_2 for a time interval t_2 , then the average acceleration $\vec{a} = \frac{a_1 t_1 + a_2 t_2}{t_1 + t_2}$

Non-Uniform Acceleration:

A body is said to have non-uniform acceleration if magnitude and direction of the acceleration both change during motion.

Instantaneous Acceleration:

Acceleration of a body at a particular instant is known as instantaneous acceleration. It is obtained from average acceleration as Δt is made smaller and smaller till it approaches zero. Mathematically, instantaneous is the limit of the ratio of the change in velocity $\Delta \vec{v}$ to the time interval Δt as Δt following the instant t approaches zero.

$$\vec{a}_{\text{ins}} = \lim_{\Delta t \rightarrow 0} \frac{\Delta \vec{v}}{\Delta t}$$

The change in velocity can occur due to change in speed or in direction or in both.

Variable Acceleration:

The acceleration of a body is said to be variable if its velocity changes with time in terms of magnitude or direction or both. The variable acceleration is also called non-uniform acceleration.

GRAPHICAL REPRESENTATION OF ACCELERATION WITH VELOCITY-TIME GRAPH

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

$$a = \frac{\Delta v}{\Delta t} = \tan \theta = \text{Slope of graph.}$$
- The area under the v-t graph gives the distance covered by object.
- In case of instantaneous acceleration, the slope of tangent at point P of the curved line in the velocity time graph shows instantaneous acceleration of the body as shown in figure a.
- When there is continuous change of velocity body with respect to time in magnitude or direction then there is a curved line in the velocity time graph which shows variable acceleration of the body as shown in figure b.

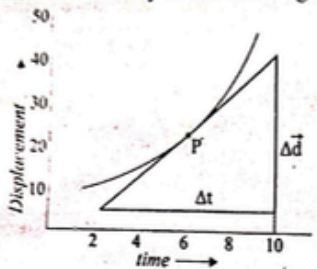


Fig.a

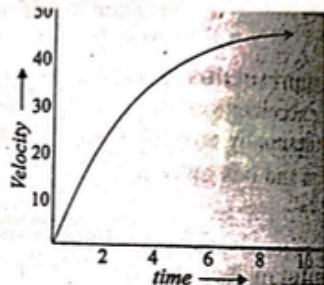
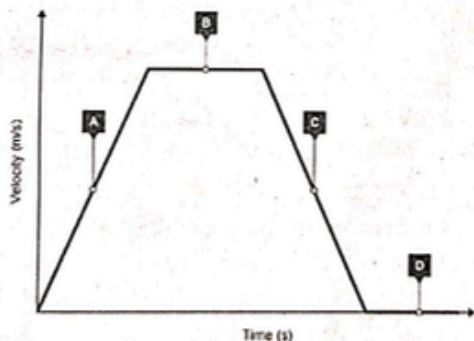
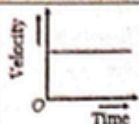
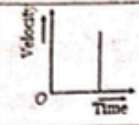

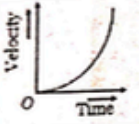

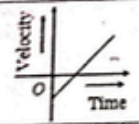
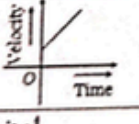
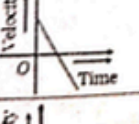

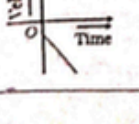


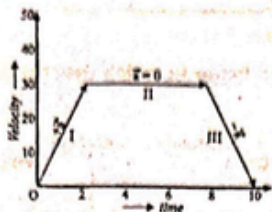
Fig.b

For Your Information:

Section of graph	Gradient	Velocity	Acceleration
A	positive	increasing	positive
B	zero	constant	zero
C	negative	decreasing	negative
D	zero	zero (at rest)	zero

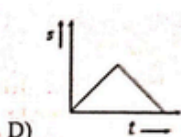
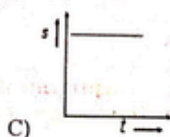
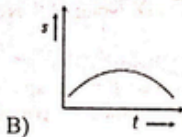
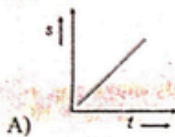
Various velocity – time graphs and their interpretation

	$\theta = 0$, $a = 0$, $v = \text{constant}$ i.e., line parallel to time axis represents that the particle is moving with constant velocity.
	$\theta = 90^\circ$, $a = \text{infinite}$, $v = \text{increasing}$ i.e., line perpendicular to time axis represents that the particle is increasing its velocity, but time does not change. It means the particle possesses infinite acceleration. Practically it is not possible
	$\theta = \text{constant}$, so $a = \text{constant}$ and v is increasing uniformly with time i.e., line with constant slope represents uniform acceleration of the particle.
	θ increasing so acceleration increasing i.e., line bending towards velocity axis represent the increasing acceleration in the body.
	θ decreasing so acceleration decreasing i.e. line bending towards time axis represents the decreasing acceleration in the body.
	Positive constant acceleration because θ is constant and $< 90^\circ$ but initial velocity of the particle is negative.
	Positive constant acceleration because θ is constant and $< 90^\circ$ but initial velocity of particle is positive
	Negative constant acceleration because θ is constant and $> 90^\circ$ but initial velocity of the particle is positive
	Negative constant acceleration because θ is constant and $> 90^\circ$ but initial velocity of the particle is zero.
	Negative constant acceleration because θ is constant and $> 90^\circ$ but initial velocity of the particle is negative.

For your Information:

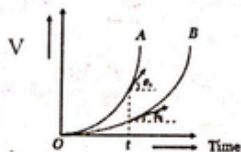
Velocity-time graph represents acceleration, uniform acceleration and deceleration.

Example: Which of the following graph represents uniform motion?



Solution: A) When distance time graph is a straight line with constant slope than motion is uniform.

Example: Velocity-time graphs of two cars which start from rest at the same time, are shown in the figure. Graph shows, that.

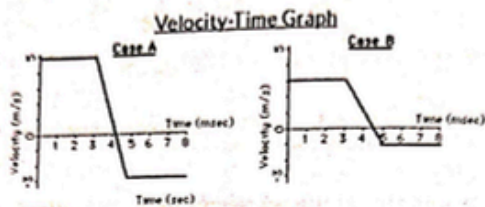


- A) Initial velocity of A is greater than the initial velocity of B
- B) Acceleration in A is increasing at lesser rate than in B
- C) Acceleration in A is greater than in B
- D) Acceleration in B is greater than in A

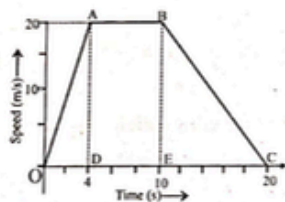
Solution: C) At a certain instant t slope of A is greater than B ($\theta_A > \theta_B$), so acceleration in A is greater than B

CRITICAL THINKING?

5. In the diagram given below in which case the acceleration is maximum



- A. Case B
B. In both cases same
C. Case A
D. None of these
6. The given figure represents the speed-time graph of a body moving in a straight line. How much distance does it travel during the last 10 seconds?



- A. 40 m
B. 80 m
C. 100 m
D. 220 m


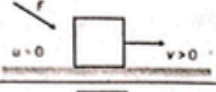



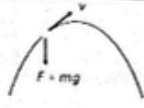
NEWTON'S LAWS OF MOTION

Force:

Force is an external effect in the form of a push or pulls which

- (i) Produces or tries to produce motion in a body at rest.
- (ii) Stops or tries to stop a moving body.
- (iii) Changes or tries to change the direction of motion of the body

For your Information:

	Body remains at rest. Here force is trying to change the state of rest.
	Body starts moving. Here force changes the state of rest.
	In a small interval of time, force increases the magnitude of speed and direction of motion remains same.
	In a small interval of time, force decreases the magnitude of speed and direction of motion remains same.
	In uniform circular motion only direction of velocity changes, speed remains constant. Force is always perpendicular to velocity.
	In non-uniform circular motion, elliptical, parabolic or hyperbolic motion force acts at an angle to the direction of motion. In all these motions. Both magnitude and direction of velocity changes.

Units:

Absolute units: (i) Newton (S.I.) (ii) Dyne (C.G.S)

Gravitational units: (i) Kilogram-force (M.K.S.) (ii) Gram-force (C.G.S)

Newton: One Newton is that force which produces an acceleration of 1m/s^2 in a body of mass 1 Kilogram. $\therefore 1\text{ newton} = 1\text{kg m/s}^2$

Dyne: One dyne is that force which produces an acceleration of 1cm/s^2 in a body of mass 1 gram. $\therefore 1\text{ Dyne} = 1\text{gm cm/sec}^2$

Relation between absolute units of force $1\text{ Newton} = 10^5\text{ Dyne}$

Newton's Laws of Motion:

First Law of Motion: (Law of Inertia): It states that everybody 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 directly proportional 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

$F \propto \text{Mass of the body} \times \text{Change in velocity per second} \propto a$

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

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

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

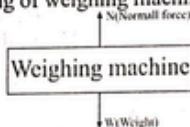
CRITICAL CONCEPT!

When a stone and leaf are dropped from a building simultaneously then why the stone reaches to the ground earlier?

Example: A man of mass 60 kg is standing on a weighing machine placed on ground. Calculate the reading of machine ($g = 10 \text{ m/s}^2$).

A. 600 N B. 400 N C. 200 N D. 100 N

Solution: A. For calculating the reading of weighing machine, we draw diagram.



$$w = mg = 60 \times 10 = 600 \text{ N}$$

Example: A player caught a cricket ball of mass 150g moving at a rate of 20 m/s. If the catching process is completed in 0.1s, the force of the blow exerted by the ball on the hand of the player is equal to:

A. 150 N B. 3 N C. 30 N D. 300 N

Solution: $F = \frac{mv}{t} = \frac{0.15 \times 20}{0.1}$
 $F = 30 \text{ N}$

Third Law of Motion (Action and Reaction Forces)

It states that to every action, there is an equal and opposite reaction.

- Action-reaction forces always occur in pairs.
- If a body A exerts a force (action) on a body B, then B will exert an equal and opposite force (reaction) on A.
- When a force acts on a body then the reaction acts normally to the surface of the body.
- Action and reaction forces never balance each other.
- Newton's laws are not valid on the microscopic objects such as electrons, proton, neutron etc. This is because these particles have small masses but large velocity. When they move they behave and wave? But Newton's laws can apply only for linear motion.

CRITICAL THINKING ?

7. Newton's third law concerns the forces of interaction between two bodies. Which of the following statements relating to the third law is not correct?
- The two forces must be of the same type
 - The two forces must act on different bodies
 - The two forces are always opposite in direction
 - The two forces are equal and opposite so the bodies are in equilibrium
8. A wooden block of mass 0.60kg is on a rough horizontal surface. A force of 12 N is applied to the block and it accelerates at 4.0ms^{-2} . What is the magnitude of the frictional force acting on the block?



- 2.4N
- 9.6N
- 14N
- 16N

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

$$p \propto v \qquad p \propto m$$
- $p = 0$ if $v = 0$, how massive the body may be.
SI unit of linear momentum are kg ms^{-1} or N s .
Dimension of momentum are $[\text{MLT}^{-1}]$
- If there are two bodies of different masses and velocities, but having the same momentum.

$$p_1 = p_2$$

$$m_1 v_1 = m_2 v_2$$

$$\frac{m_1}{m_2} = \frac{v_2}{v_1}$$

This result shows that at constant momentum, velocity of body is inversely proportional to its mass. Graphically, the relation between mass and velocity is shown in fig.



Topic-1

Newton's 2nd Law and Linear Momentum

Consider a body of mass m moving with an initial velocity \vec{v}_i . Suppose an external force \vec{F} acts upon it for time t after which velocity becomes \vec{v}_f . The acceleration \vec{a} produced by this force is given by

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t}$$

By Newton's second law, the acceleration is given as

$$\vec{a} = \frac{\vec{F}}{m}$$

Equating the two expressions of acceleration, we have

$$\frac{\vec{F}}{m} = \frac{\vec{v}_f - \vec{v}_i}{t}$$

or

$$\vec{F} \times t = m \vec{v}_f - m \vec{v}_i = \text{Impulse} \quad \dots\dots\dots (i)$$

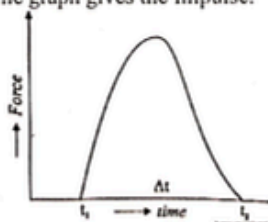
Where $m \vec{v}_i$ is the initial momentum and $m \vec{v}_f$ is the final momentum of the body.

The equation (i) shows that change in momentum or Impulse is equal to the product of force and the time for which force is applied. This form of the second law is more general than the form $\vec{F} = m \vec{a}$, because it can easily be extended to account for changes as the body accelerates when its mass also changes. For example, as a rocket accelerates, it loses mass because its fuel is burnt and ejected to provide greater thrust.

From Equation (i)
$$\vec{F} = \frac{m \vec{v}_f - m \vec{v}_i}{t}$$

Thus, second law of motion can also be stated in terms of momentum as follows. Time rate of change of momentum of a body equals the applied force.

- The area under Force and time graph gives the Impulse.



- If two forces F_1 and F_2 act on a body to produce the same impulse, then their respective times of applications t_1 and t_2 should be such that

$$F_1 t_1 = F_2 t_2$$

$$\frac{t_1}{t_2} = \frac{F_2}{F_1}$$

For Your Information:

Impulsive force is a force which acts on a body for a very short time.

For example :

- A bat hitting the ball
- The collision between two snooker balls
- Air bag in the automobiles have saved countless lives in accidents. The air bag increases the time interval during which the passenger is brought to rest, thereby decreasing the force on the passenger.
- Train bogies are provided with buffers
- Automobiles are provided with spring systems

CRITICAL THINKING

- What is the momentum of a runner of mass 65 kg who covers a displacement of 100m in 40 sec?
 - 162 kg ms⁻¹
 - 140 kg ms⁻¹
 - 150 kg ms⁻¹
 - 155 kg ms⁻¹
- If a force of 250 N act on body, the momentum acquired is 125 kg-m/s. What is the period for which force acts on the body?
 - 0.5 sec
 - 0.1 sec.
 - 0.2 sec
 - 0.4 sec

LAW OF CONSERVATION OF LINEAR MOMENTUM**Isolated system:**

In the absence of an external and unbalanced force, when two or more than to bodies are exerted the forces to one another during their collision is called isolated system.

In an **isolated** system $(p_i)_{total} = (p_f)_{total}$

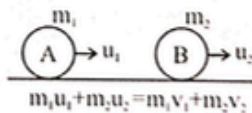
$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

The total linear momentum of an isolated system remains constant.

- If there is a system of particles free from external resultant force, $\vec{p}_1, \vec{p}_2, \vec{p}_3, \dots$ being the linear momentum of its individual particle then $\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \dots = \text{constant}$

Thus, for a system of particles the total linear momentum cannot change, unless an external resultant force acts on the system.

The principle of the conservation of linear momentum states that, if no external forces act on a system of colliding objects, the total momentum of the objects in a given direction before collision = total momentum in same direction after collision

**Example:**

Two railway trucks of mass m and $3m$ move towards each in opposite directions with speeds $2v$ and v respectively. These trucks collide and stick together.

What is the speed of the trucks after the collision?

- $\frac{v}{4}$
- $\frac{v}{2}$
- v
- $\frac{5v}{4}$

Solution: A. Momentum before collision = momentum after collision

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2) v'$$

$$m(2v) + 3m(-v) = (m + 3m) v'$$

$$-mv = 4mv' \Rightarrow v' = -\frac{1}{4}v$$

CRITICAL THINKING

11. A body, initially at rest, explodes into two masses M_1 and M_2 that move apart with speeds v_1 and v_2 respectively. What is the ratio $\frac{v_1}{v_2}$?

A. $\frac{M_1}{M_2}$

B. $\frac{M_2}{M_1}$

C. $\left(\frac{M_1}{M_2}\right)^{\frac{1}{2}}$

D. $\left(\frac{M_2}{M_1}\right)^{\frac{1}{2}}$

COLLISIONS

The impact of two bodies due to their interaction with each other is called collision. The magnitude and direction of the velocities of the bodies before and after collision may be same or different.

Elastic Collision	Inelastic collision
Momentum is conserved.	Momentum is conserved.
The total kinetic energy is conserved.	The total kinetic energy is not conserved.
The total energy is conserved.	The total energy is conserved.
No conversion of energy takes place.	Kinetic energy is changed into other energy such as sound or heat energy.
Examples.1 When a ball at billiard table hits another ball. 2. When you throw a ball on the ground and it bounces back to your hand.	Examples.1 Of an inelastic collision can be collision of two cars. 2. Collision of a rubber ball with a hard surface.

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 $v_1 + v'_1 = v_2 + v'_2$ or $v_1 - v_2 = -(v'_1 - v'_2)$.

Speed of approach = Speed of recession

After collision,

$$v'_1 = \frac{(m_1 - m_2)v_1}{(m_1 + m_2)} + \frac{2m_2 v_2}{(m_1 + m_2)} \quad \text{or} \quad v'_2 = \frac{2m_1 v_1}{(m_1 + m_2)} + \frac{(m_2 - m_1)v_2}{(m_1 + m_2)}$$

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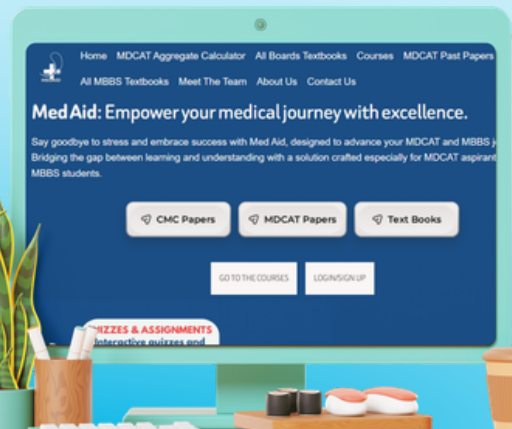
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CRITICAL THINKING?

12. In one dimensional elastic collision of two bodies of same masses, what will happen if the moving body collides with the mass which is initially at rest?
- Their velocities will be interchanged
 - Velocities of both bodies will be zero
 - Moving body will continue its motion
 - Moving body will come at rest and the mass at rest will start its motion

PROJECTILE MOTION

Projectile Motion

- Projectile motion is a two-dimensional motion. The motion of the particle is constrained in a plane.
- When a particle is thrown obliquely near the earth's surface it moves in a parabolic path, provided the particle remains close to the surface of earth and the air resistance is negligible. This is an example of projectile motion.
- Assumptions of Projectile Motion.**
 - There is no resistance due to air.
 - The effect due to curvature of earth is negligible.
 - The effect due to rotation of earth is negligible.
 - For all points of the trajectory, the acceleration due to gravity 'g' is constant in magnitude and direction.

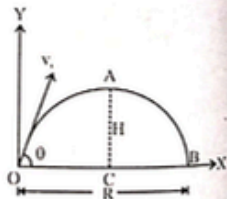
Principles of Physical Independence of Motions:

- The motion of a projectile is a two-dimensional motion. So, it can be discussed in two parts. Horizontal motion and vertical motion. These two motions take place independent of each other. This is called the principle of physical independence of motions.
- The velocity of the particle can be resolved into two mutually perpendicular components. Horizontal component and vertical component.
- The horizontal component remains unchanged throughout the flight. The force of gravity continuously affects the vertical component.

Terms Used in Projectile Motion:

Figure shows a particle projected from the point "O" with an initial velocity " v_i " at an angle θ with the horizontal.

- The point O is called the point of projection.
- The angle " θ " is called the "angle of projection".
- The distance OB is called the, horizontal range (R) or simply range, the vertical height AC is called maximum height (H) or Vertical Range.
- The total time taken by the particle in describing the path OAB is called the time of flight (T).
- Horizontal and vertical coordinates of projectile at time 't' are given as; $x = v_i \cos \theta t$ and $y = v_i \sin \theta t - \frac{1}{2} gt^2$
- Trajectory of projectile is parabola in the absence of air friction.



- If two identical balls are thrown simultaneously from same height, one vertically and other horizontally, then both falls to the earth simultaneously.

Velocity of projectile

$$v = \sqrt{v_i^2 + g^2 t^2} - 2v_i \sin \theta g t$$

Direction of the resultant velocity

$$\tan \phi = \frac{v_y}{v_x}$$

$$\tan \phi = \frac{v_i \sin \theta - g t}{v_i \cos \theta}$$

Time of flight:

- Time to reach maximum height is given as; $t = \frac{v_i \sin \theta}{g}$
- Total time of flight is given as; $T = \frac{2v_i \sin \theta}{g}$

Maximum Height:

- Vertical range (height) is given as; $H = \frac{v_i^2 \sin^2 \theta}{2g}$

Horizontal range:

- 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;

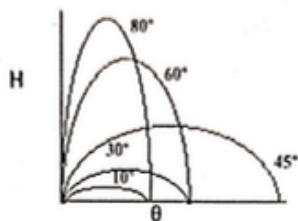
$$R = \frac{v_i^2 \sin 2\theta}{g} = \frac{v_i^2 (2 \sin \theta \cos \theta)}{g}$$

- Maximum horizontal range is at angle $\theta = 45^\circ$ and given as; $R_{\max} = \frac{v_i^2}{g}$
- The relation between range and the height of the projectile is $R \tan \theta = 4H$
- The relation between maximum T and H is $H = gT^2/8$
- 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. $\theta_1 + \theta_2 = 90^\circ$
- Energy of projectile: When a projectile moves upward its kinetic energy decreases, potential energy increases but the total energy always remain constant. If a body is projected with initial kinetic energy $K.E = 1/2 mv_i^2$ with angle of projection θ with the horizontal then at the highest point of trajectory.

$$K.E = 1/2 mv_i^2 \cos^2 \theta$$
- At maximum height the $K.E = K.E_i \cos^2 \theta$
- Potential energy $= mgH = mg \left(\frac{v_i^2 \sin^2 \theta}{2g} \right) = 1/2 mv_i^2 \sin^2 \theta$
- Total energy = Kinetic energy + Potential energy $= 1/2 mv_i^2 \cos^2 \theta + 1/2 mv_i^2 \sin^2 \theta$
 $= 1/2 mv_i^2 = \text{Energy at the point of projection}$

This is in accordance with the law of conservation of energy

- Variation in the range and height with angle of projection is shown with the following sketch for same speed of projectile.



- When angle of projection is 45° then range and maximum height of projectile are equal each other.
- The path of a projectile is parabolic.
- At the lowest point, the linear momentum is $p = mv$

Application to Ballistic Missile

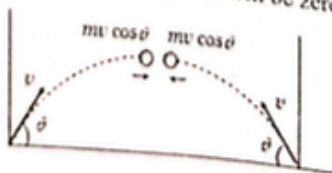
- An **un-powered** and **un-guided** missile is called ballistic missile
- Friction of air affects the horizontal and vertical motion of the missile
- Ballistic missiles are useful only for short ranges.
- Powered and remote control guided missiles are used for long ranges and precision.

Example:

Two equal masses (m) are projected at the same angle (θ) from two points separated by their range with equal velocities (v). The momentum at the point of their collision is

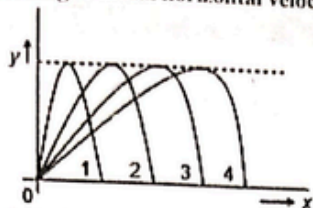
- A) Zero B) $2mv \cos \theta$ C) $-2mv \cos \theta$ D) None of these

Solution: A) Both masses will collide at the highest point of their trajectory with equal and opposite momentum. So net momentum of the system will be zero



Example:

Figure shows four paths for a kicked football. Ignoring the effects of air on the flight, rank the paths according to initial horizontal velocity component, highest first



A) 1, 2, 3, 4

B) 2, 3, 4, 1

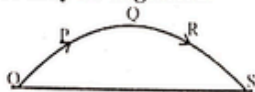
C) 3, 4, 1, 2

D) 4, 3, 2, 1

Solution: D) Range directly proportional to horizontal component of velocity. Graph 4 shows maximum range, so football possess maximum horizontal velocity in this case.

CRITICAL THINKING ?

13. A body is projected with kinetic energy K at an angle of 60° with the horizontal. Its kinetic energy at the highest point of its trajectory will be
- A. $2K$ B. K
 C. $\frac{K}{2}$ D. $\frac{K}{4}$
14. Four projectiles are projected with the same speed at angles 20° , 35° , 60° and 75° with the horizontal. The range will be the longest for the projectile whose angle is
- A. 20° B. 35°
 C. 60° D. 75°
15. A projectile is launched at point O and follows the path $OPQRS$, as shown. Air resistance may be neglected.



16. Which statement is true for the projectile when it is at the highest point Q of its path?
- A. The horizontal component of the projectile's acceleration is zero
 B. The horizontal component of the projectile's velocity is zero
 C. The kinetic energy of the projectile is zero
 D. The momentum of the projectile is zero

TOPIC-2 \gg WORK AND ENERGY

COURSE CONTENT

- Work
- Energy
- Kinetic energy
- Potential energy
- Gravitational potential energy
- Power
- Work Energy Principle
- Explain the work done against friction is dissipated as heat in the environment
- Implications of energy losses in practical devices

WORK

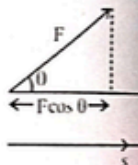
The work done by a force in displacing an object is defined as the product of displacement and the component of the force in the direction of the displacement is work.

$W = (\text{Component of force in the direction of displacement}) (\text{displacement})$

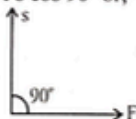
$W = (F \cos\theta) (s)$

$W = F s \cos\theta$. F is force, s is displacement and θ is angle between F and s .

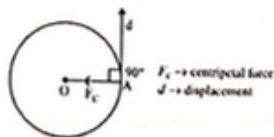
- **Maximum work:** If $\theta = 0^\circ$ Then $W = F s \cos 0^\circ$ or $W = F s$. It is the maximum value of work.



- **Zero Work:** If $\theta = 90^\circ$ Then $W = F s \cos 90^\circ$ or, $W = 0$, so work is zero



- If displacement is zero, then the work done is zero. Also, if applied force and displacement are perpendicular to each other, the work done is zero.
- For example:
 - (a) Pushing against a wall does zero work because displacement is zero.
 - (b) The work done by the centripetal force along the radius of the circular path is zero



- Negative work: If $\theta = 180^\circ$ Then $W = F s \cos 180^\circ$ or, $W = -F s$



So, work is negative.

- In S.I the unit of work is joule (J) and in C.G.S the unit of work is erg.
Do you know?

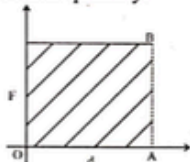
If nothing is actually moving, no work is done no matter how great the force involved.

CRITICAL CONCEPT!

The work done is 100% when the applied force is acting at angle 0 in the direction of displacement, what would be angle of applied force with displacement when work done is 50%

Work Done by Constant Force:

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



Work done = Area of rectangle = (OA) (AB) = (F) (d)

Work Done by a Variable Force

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

Example:

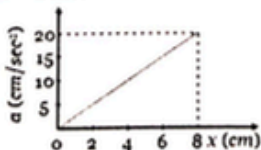
A box of mass 1 kg is pulled on a horizontal plane of length 1 m by a force of 8 N then it is raised vertically to a height of 2m, the net work done is

- A) 28 J B) 8 J C) 18 J D) None of above

Solution: A) Work done to displace it horizontally = $F \times s = 8 \times 1 = 8$ J Work done to raise it vertically $F \times s = mgh = 1 \times 10 \times 2 = 20$ J hence, Net work done = $8 + 20 = 28$ J

Example:

A 10 kg mass moves along x-axis. Its acceleration as a function of its position is shown in the figure. What is the total work done on the mass by the force as the mass moves from $x = 0$ to $x = 8$ cm?



- A) 8 J B) 8×10^2 J C) 16×10^2 J D) 4×10^3 J

Topic-2

Solution: Work done on the mass = mass \times covered area between the graph and displacement axis on a-x graph

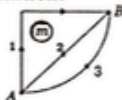
$$= 10 \times \frac{1}{2} (8 \times 10^{-2}) \times 20 \times 10^{-2} = 8 \times 10^{-2} \text{ J}$$

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. $W_{\text{total}} = 0$
- (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.

Example:

If W_1 , W_2 and W_3 represent the work done in moving a particle from A to B along three different paths 1, 2 and 3 respectively (as shown) in the gravitational field of a point mass m , find the correct relation.



A) $W_1 = W_2 = W_3$

B) $W_1 > W_2 > W_3$

C) $W_1 < W_2 < W_3$

D) none of these

Solution: A) As gravitational field is conservative in nature. So work done in moving a particle from A to B does not depend upon the path followed by the body. It always remains same.

For Your Information:

We can calculate the work done by a force on an object, but that force is not necessarily the cause of the displacement. For example, if you lift a body, work is done on the object by the gravitational force, although gravity is not the cause of the object moving upward.

CRITICAL THINKING

1. A man pulling a bag with force of 15N at angle 60° with horizontal plane. If bag covers a distance of 10m, then work done by the man is
A. 50J
B. 75J
C. 150J
D. 100J
2. The adjoining diagram shows the velocity versus time plot for a particle. The work done by the force on the particle is positive from



A. B to C

B. D to E

C. A to B

D. C to D

ENERGY

The word energy is derived from the Greek word "Energeia" which means work. Energy of a body is defined as its ability to do work. Units of energy are the same as that of work. The SI unit of energy is joule. Other units of energy are erg, foot-pound and kilowatt-hour etc. energy occurs in many forms such as mechanical, electrical, chemical, nuclear, magnetic, heat and elastic energy etc. energy possessed by a body is basically of two types: Kinetic energy and Potential energy.

Do you know?

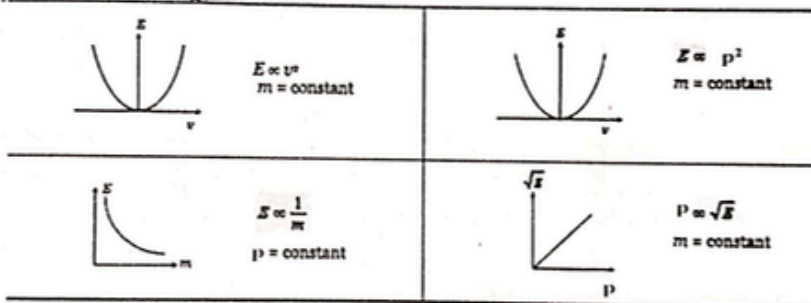
One minute of Sunshine supplies enough energy to meet the earth's needs for a whole year.

KINETIC ENERGY

$$K.E = \frac{1}{2}mv^2$$

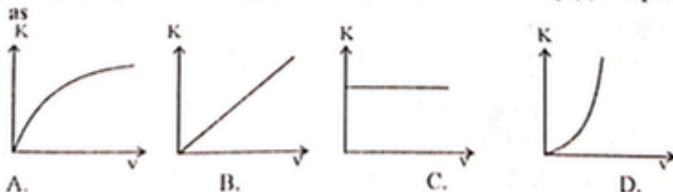
- Relation between linear momentum (p) and kinetic energy: $p^2 = 2m \text{ K.E}$
- For two bodies having equal momentum $\frac{K.E_1}{K.E_2} = \frac{m_2}{m_1}$
- For two bodies having equal kinetic energies: $\frac{p_1}{p_2} = \sqrt{\frac{m_1}{m_2}}$

Graphs of kinetic Energy:



CRITICAL THINKING

- A bullet of mass 20g is fired with velocity of 2000 ms^{-1} , the K.E of the bullet is
 A. 2000 J
 B. 4000 J
 C. 20000 J
 D. 40000 J
- The graph of kinetic energy (K.E) of the body versus velocity (v) is represented by



Example:

From a water fall, water is falling at the rate of 100 kg/s on the blades of turbine. If the height of the fall is 100m then the power delivered to the turbine is approximately equal to

- A) 100 kW
 B) 10 kW
 C) 1 kW
 D) 1000 kW

Solution: A)

$$\text{Power} = \frac{\text{work done}}{t} = \frac{mgh}{t} = 100 \times 10 \times 100 = 10^5 \text{ watt} = 100 \text{ kW} \quad \left[\text{As } \frac{m}{t} = 100 \frac{\text{kg}}{\text{sec}} (\text{given}) \right]$$

CRITICAL THINKING?

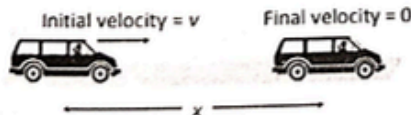
6. What is the power of an electric motor when it consumes energy of $9 \times 10^3 \text{ J}$ in 3 s?
 A. 1 hp
 B. 2 hp
 C. 3 hp
 D. 4 hp
7. A man does a given amount of work in 10 sec. Another man does the same amount of work in 20 sec. The ratio of the output power of first man to the second man is
 A. 2/1
 B. 1/2
 C. 1
 D. 4/1

WORK ENERGY PRINCIPLE

$$\text{Work done} = \text{Change in kinetic energy} = K.E_f - K.E_i \quad \text{or} \quad W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

Stopping of Vehicle by Retarding Force:

If a vehicle moves with some initial velocity and due to some retarding force it stops after covering some distance after some time.



CRITICAL CONCEPT!

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

(1) Stopping distance:

Let m = Mass of vehicle, v = Velocity, P = Momentum, E = Kinetic energy F = Stopping force, S = Stopping distance, t = Stopping time

Then, in this process stopping force does work on the vehicle and destroy the motion. By the work-energy theorem

$$W = \Delta K.E = \frac{1}{2}mv^2$$

⇒ (Stopping force F) (Distance S) = Kinetic energy (E)

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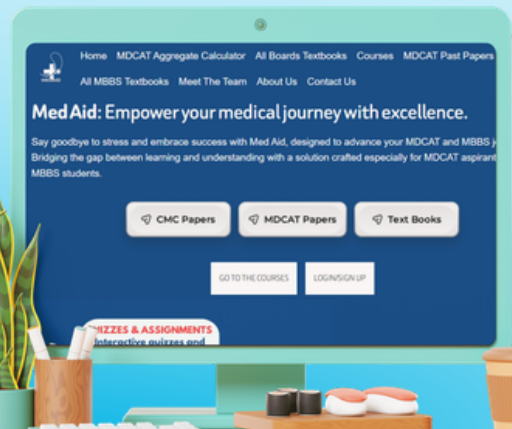
Review Your Mistakes

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Topic-2

$$\Rightarrow \text{Stopping distance (S)} = \frac{\text{Kinetic Energy (K.E)}}{\text{Stopping Force (F)}}$$

$$S = \frac{mv^2}{2F}$$

(2) Stopping time:

By the impulse-momentum theorem $F \times t = \Delta P \Rightarrow F \times t = P$

$$\therefore t = \frac{P}{F}$$

$$\text{or } t = \frac{mv}{F}$$

(3) Comparison of stopping distance and time for two vehicles:

Two vehicles of masses m_1 and m_2 are moving with velocities v_1 and v_2 respectively. When they are stopped by the same retarding force (F).

$$\text{The ratio of their stopping distances } \frac{S_1}{S_2} = \frac{K.E_1}{K.E_2} = \frac{m_1 v_1^2}{m_2 v_2^2}$$

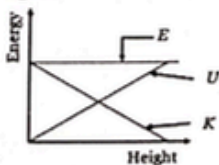
$$\text{and the ratio of their stopping time } \frac{t_1}{t_2} = \frac{P_1}{P_2} = \frac{m_1 v_1}{m_2 v_2}$$

If vehicles possess same velocities $v_1 = v_2$	If vehicle possess same kinetic momentum $p_1 = p_2$	If vehicle possess same kinetic energy $K.E_1 = K.E_2$
$\frac{S_1}{S_2} = \frac{m_1}{m_2}$	$\frac{S_1}{S_2} = \frac{K.E_1}{K.E_2} = \left(\frac{p_1^2}{2m_1}\right) \left(\frac{2m_2}{p_2^2}\right) = \frac{m_2}{m_1}$	$\frac{S_1}{S_2} = \frac{K.E_1}{K.E_2} = 1$
$\frac{t_1}{t_2} = \frac{m_1}{m_2}$	$\frac{t_1}{t_2} = \frac{p_1}{p_2} = 1$	$\frac{t_1}{t_2} = \frac{p_1}{p_2} = \frac{\sqrt{2m_1 K.E_1}}{\sqrt{2m_2 K.E_2}} = \frac{\sqrt{m_1}}{\sqrt{m_2}}$

- E.P.E = $\frac{1}{2} k x^2$

Energy height graph:

When a body projected vertically upward from the ground level with some initial velocity then it possess kinetic energy but its potential energy (U) is zero. As the body moves upward its potential energy increases due to increase in height but kinetic energy decreases (due to decrease in velocity). At maximum height its kinetic energy becomes zero and potential energy maximum but throughout the complete motion total energy remains constant as shown in the figure.



WORK DONE AGAINST FRICTION IS DISSIPATED AS HEAT IN THE ENVIRONMENT**Conservation of Energy:**

Energy cannot be destroyed. It can be transformed from one form into another, but total amount of energy remains 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 energy at each instance is always **conserved**.

Kinetic energy + Potential energy = constant

Work done against friction dissipated as heat in the environment

- If a body is dropped from height 'h' to earth's surface in **absence of air**, then;
Loss in P.E. = Gain in K.E.

$$mg(h_1 - h_2) = \frac{1}{2}m(v_2^2 - v_1^2)$$

- 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.

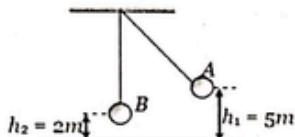
$$mgh = \frac{1}{2}mv^2 + fh$$

- 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.

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

Example:

A boy is sitting on a swing at a maximum height of 5m above the ground. When the swing passes through the mean position which is 2m above the ground its velocity is approximately



A) 7.6 m/s

B) 9.8 m/s

C) 6.26 m/s

D) None of these

Solution:

$$V = \sqrt{2g(h_1 - h_2)} = \sqrt{2 \times 9.8 \times 3} = 7.6 \text{ms}^{-1}$$

CRITICAL THINKING

8. A trolley runs from P to Q along a track. At Q, its potential energy is 50 kJ less than at P.



At P, the kinetic energy of the trolley is 5 kJ. Between P and Q the work that the trolley does against friction is 10 kJ. What is the kinetic energy of the trolley at Q?

A. 35 kJ

B. 55 kJ

C. 45 kJ

D. 65 kJ

IMPLICATIONS OF ENERGY LOSSES IN PRACTICAL DEVICES

- Mechanical efficiency is the ratio of work output to work input.
- The efficiency of an ideal machine is 100 percent but an actual machine's efficiency will always be less than 100%.
- If a machine moves a load through a distance h then the useful work done by the machine is called output.
Output = Load \times distance h through which the load moves = $F_{out} \times D_{out}$
- If an effort F_{in} acts through a distance D_{in} then the work done on the machine is called input.
Input = Effort force \times Effort distance.
Input = $F_{in} \times D_{in}$
- The ratio of output to the input of a machine is called its efficiency.

$$\begin{aligned} \text{Efficiency} &= \frac{\text{out put work}}{\text{in put work}} \\ \text{Mathematically} &= \frac{\text{Load force} \times \text{Load distance}}{\text{Effort force} \times \text{Effort distance}} \end{aligned}$$

$$\text{Efficiency} = \frac{F_{out} \times D_{out}}{F_{in} \times D_{in}}$$

The equation for percentage efficiency is

$$\begin{aligned} \text{Percentage Efficiency} &= \frac{\text{Output work}}{\text{Input work}} \times 100\% = \frac{W_{out}}{W_{in}} \times 100\% \\ &= \frac{F_{out} \times D_{out}}{F_{in} \times D_{in}} \times 100\% \end{aligned}$$

- Even a very efficient device will waste some of its input energy in the form of heat due to the friction forces between different parts of machine.
- An incline is used as a simple machine. Which is a flat surface tilted at an angle. Which is commonly used to load truck, planes and trains.

Table	
Practical devices	Efficiency
Petrol heat engine	(25-30)%
Diesel engine	(34-40)%
Steam locomotive	(35-40)%
Incandescent lamp	5%
Fluorescent lamp	20%
Steam turbine	(34-46)%
Air craft gas turbine	36%
Nuclear power plant	(30-35)%
Fossil fuel power plant	(30-40)%
Electric generator	(70-98)%
Electric motor	(50-92)%
Dry cell battery	90%
Battery	90%
Home coal furnace	55%

FOR YOUR INFORMATION:

Efficiency of some electrical equipment's: LED light bulbs have been introduced to replace ordinary light bulbs, as they are much more efficient. Let's take a look at a standard 50-watt. The energy consumption to use a light bulb like this would cost about 1278 Rs in a year. An LED, running over the course of 1 year would cost only 260Rs to operate. Using these causes less energy to be wasted as heat. Recently developed, AC/DC fans can operate on less energy while producing a high airflow. In fact, they can cut down your power consumption by up to 65% and can operate on solar panel. AC/DC fans are designed to run on 12V and consume around 26-35W. Ordinary Fan consume 75watt while AC/DC fans consume about 35 to 40watt so AC/DC fans are more efficient.



Example

A machine needed 1000J of energy to raise a 10kg block at a distance of 6.0m. What is the machine efficiency?

- (A) 40% (B) 49%
(C) 59% (D) 50%

Solution: First, find the work done to raise the block: $W = mgh$

$$= 10\text{kg} \times 9.8\text{m/s}^2 \times 6.0\text{m} = 588\text{J}$$

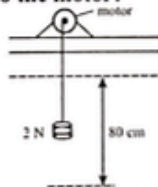
$$\text{Efficiency} = \eta = \frac{\text{Output work}}{\text{Input work}} \times 100\% = \frac{588}{1000} \times 100\% = 58.8\% = 59\%$$

Pulleys are machines used to lift heavy loads. Modern cranes are complicated form of pulley system.

$\eta = 59\%$ Answer

CRITICAL THINKING?

9. A small electric motor is used to raise a weight of 2.0 N through a vertical height of 80 cm in 4.0 s. The efficiency of the motor is 20%. What is the electrical power supplied to the motor?



- A. 0.080 W B. 2.0 W
C. 0.80 W D. 200 W

The matter in 0.453 kg of anything, when it is completely converted into energy according to, $E = mc^2$, will produce 11400 million kilowatt-hours of energy.



COURSE CONTENT

- Angular displacement (Revolution, Degree, Radian)
- Angular velocity
- Relation between linear and angular variables
- Relation between linear and angular displacements
- Relation between linear and angular velocities
- Relation between linear and angular accelerations
- Centripetal force (centripetal acceleration)

ANGULAR DISPLACEMENT (REVOLUTION, DEGREE, RADIAN)

Circular Motion

"Motion of bodies in circular path is called circular motion."

- During uniform circular motion, the direction of position vector changes continuously but the magnitude remains constant which is equal to r (radius of circular path)
- In circular motion, the direction of velocity change at every point but its magnitude remains constant.
- For one complete revolution, the angular displacement is 2π and time taken is T (time period). So angular velocity $\omega = \frac{2\pi}{T}$.
- Speed, kinetic energy and angular momentum remain constant in circular motion.

Angular Motion

"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."

The following are the properties of angular displacement

- It depends upon length of arc.
- For very small angle it is a vector quantity.
- For anti-clock wise rotation, angular displacement is positive.
- For clockwise rotation, angular displacement is negative.
- Angular displacement has direction along axis of rotation and can be determined by right hand rule

Radian

- 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.
- $2\pi \text{ rad} = 360^\circ = 1 \text{ Revolution}$
- $1^\circ = \frac{\pi}{180} \text{ rad} = 0.0174 \text{ rad}$, $1 \text{ rad} = 57.3^\circ$, $1 \text{ rad} = 0.159 \text{ rev}$
- Non S.I units are also used which are "degree" and "rev".

Revolution: When a particle completes one round trip along a circular path of a circle, then it is called one revolution.

Degree: When a circle is divided into 360° equal parts then each part is known as one degree.

Radian: One radian is the angle subtended at the centre of a circle by an arc whose length is equal to radius of the circle.

For Your Information:

- Angle swept by a minute hand in one complete rotation is 360° .
- Angle swept by minute hand in one minute is 6° .
- Angle swept by minute hand in 5 minutes is $5 \times 6^\circ = 30^\circ$

Example.1

Khawar goes around a circular track that has a diameter of 20m. If he runs around the entire track for a distance of 160m, what is his angular displacement.

Solution: $S = 160 \text{ m}$

$$r = \frac{d}{2} = \frac{20}{2} = 10 \text{ m}$$

$$\theta = \frac{s}{r} = \frac{160}{10} = 16 \text{ rad}$$

Example.2

(a) Convert the following angles from degrees to radians: $30^\circ, 45^\circ$

(b) Convert the following angles from radian to degree: $\frac{2\pi}{3}, 1$

Solution: (a) $1 \text{ rad} = \frac{180^\circ}{\pi}$ or $1^\circ = \frac{\pi}{180} \text{ rad}$

$$30^\circ = 30^\circ \times \frac{\pi}{180} = \frac{\pi}{6} \text{ rad}$$

$$45^\circ = 45^\circ \times \frac{\pi}{180} = \frac{\pi}{4} \text{ rad}$$

$$(b) \frac{2\pi}{3} = \frac{2\pi}{3} \times \frac{180^\circ}{\pi} = 120^\circ$$

$$1 = 1 \times \frac{180^\circ}{\pi} = 57.3^\circ$$

CRITICAL THINKING?

- Ali goes around a circular track that has a diameter of 20m. If he runs around the entire track for a distance of 160m, what is his angular displacement?

A. 16 rad	B. 10 rad
C. 5 rad	D. 8 rad
- 85.95 degree in terms of radian is

A. $\frac{1}{2}$ rad	B. 1 rad
C. 1.5 rad	D. 2 rad

ANGULAR VELOCITY

"Rate of change of angular displacement is called angular velocity."

$$\omega_{av} = \frac{\Delta\theta}{\Delta t}, \text{ usually not a vector quantity or } \vec{\omega}_{av} = \lim_{\Delta t \rightarrow 0} \frac{\Delta\theta}{\Delta t}, \text{ always vector quantity.}$$

- Tangential and angular velocities are related as $\vec{v} = \vec{\omega} \times \vec{r}$ or $v = \omega r$
- S.I unit of angular velocity is rad s^{-1} .
- The magnitude of an angular velocity is called the angular speed which is also represented by ω .

Example: The angular velocity of seconds hand of a watch will be

A) $\frac{\pi}{60}$ rad/sec

C) 60π rad/sec

B) 30π rad/sec

D) $\frac{\pi}{30}$ rad/sec

Solution: We know that second's hand completes its revolution (2π) in 60 sec

$$\therefore \omega = \frac{\theta}{t} = \frac{2\pi}{60} = \frac{\pi}{30} \text{ rad/sec}$$

Angular Acceleration:

- The rate of change of angular velocity is defined as angular acceleration. If particle has angular velocity ω_1 at time t_1 and angular velocity ω_2 at time t_2 then

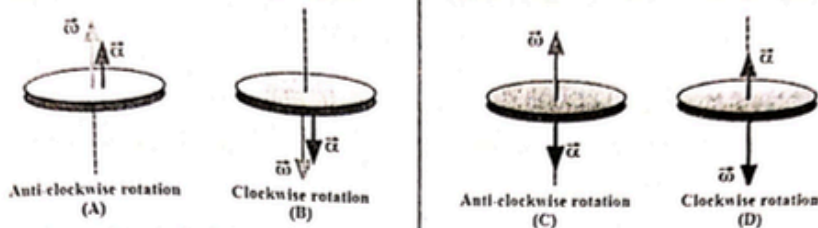
$$\text{Angular acceleration} = \vec{\alpha} = \frac{\vec{\omega}_2 - \vec{\omega}_1}{t_2 - t_1}$$

- Instantaneous angular acceleration = $\vec{\alpha} = \lim_{\Delta t \rightarrow 0} \frac{\Delta\omega}{\Delta t}$
- Unit: rad/sec^2
- Average angular acceleration = $\alpha_{av} = \frac{\omega_2 - \omega_1}{t_2 - t_1}$

Rigid Body:

- Nobody in the universe is perfectly rigid. However, the bodies in which the distance between any two particles does not change with respect to time are taken as rigid bodies.
- There are two types of motion of a rigid body.
 - (i) Translatory motion (Linear motion).
 - (ii) Rotatory Motion.

Direction of Angular Acceleration



When the angular velocity is increasing, the angular acceleration vector points in the same direction as the angular velocity, as shown in Fig. (A) and (B).

When the angular velocity is decreasing, the angular acceleration vector points in the direction opposite to the angular velocity, as shown in Fig. (C) and (D).

CRITICAL THINKING?

- A body moves with constant angular velocity in a circle. Magnitude of angular acceleration is
 - $r\omega^2$
 - Constant
 - 0
 - $r\omega$
- If a wheel turns with constant angular speed then:
 - Each point on its rim moves with constant velocity
 - Each point on its rim moves with constant acceleration
 - The angle through which the wheel turns in each second decreases as time goes on
 - The wheel turns through equal angles in equal times

RELATION BETWEEN LINEAR AND ANGULAR VARIABLES

- Relation between linear and angular displacements: $s = r\theta$
Vector form is given by $\vec{S} = \vec{\theta} \times \vec{r}$
- Relation between linear and angular velocities: $v = r\omega$
Vector form is given by $\vec{v} = \vec{\omega} \times \vec{r}$
- Relation between linear and angular accelerations: $a = r\alpha$
 $\vec{a} = \vec{\alpha} \times \vec{r}$

CRITICAL THINKING?

- The relation between linear and angular acceleration is
 - $\vec{\alpha} = \vec{a} \times \vec{r}$
 - $\vec{a} = \vec{r} \times \vec{\alpha}$
 - $\vec{a} = \vec{\alpha} \times \vec{r}$
 - $\vec{r} = \vec{\alpha} \times \vec{a}$

Analogy Between Translatory Motion And Rotatory Motion

<ul style="list-style-type: none"> ★ Linear velocity, $\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$ ★ Linear displacement, \vec{d} ★ Acceleration or linear acceleration, $\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$ ★ Mass, m ★ Linear momentum, $\vec{p} = m\vec{v}$ ★ Impulse, I or $J = \vec{F} \times \Delta t$ ★ Force, $\vec{F} = m\vec{a} = \frac{\Delta \vec{p}}{\Delta t}$ ★ Work, $W = \vec{F} \cdot \vec{d}$ ★ Kinetic energy, $K.E = \frac{1}{2}mv^2$ ★ Newton's laws in linear motion First law As $F = 0$ then $v = \text{constant}$ or $v = 0$ Second Law $\vec{F} = m\vec{a}$ Third Law $\vec{F}_{12} = -\vec{F}_{21}$ 	<ul style="list-style-type: none"> Angular velocity, $\vec{\omega} = \frac{\Delta \vec{\theta}}{\Delta t}$ Angular displacement, $\vec{\theta}$ Angular acceleration, $\vec{\alpha} = \frac{\Delta \vec{\omega}}{\Delta t}$ Moment of inertia, $I = mr^2$ Angular momentum, $\vec{L} = I\vec{\omega}$ Angular impulse = $\vec{\tau} \times \Delta t$ Torque, $\vec{\tau} = I\vec{\alpha} = \frac{\Delta \vec{L}}{\Delta t}$ Rotational work, $W_r = \tau\theta$ Kinetic energy of rotation, $K.E_r = \frac{1}{2}I\omega^2$ Newton's laws in rotational motion First law As $\tau = 0$ then $\omega = \text{constant}$ or $\omega = 0$ Second Law $\vec{\tau} = I\vec{\alpha}$ Third Law $\vec{\tau}_{12} = -\vec{\tau}_{21}$
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CENTRIPETAL FORCE (CENTRIPETAL 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.
- In vector form, centripetal force and acceleration can be written as;

$$\vec{F}_c = -m\vec{r}\omega^2 = -m\vec{r}\omega^2 = -\left(\frac{mv^2}{r}\right)\hat{r} = -\left(\frac{mv^2}{r^2}\right)\vec{r} \quad \text{or} \quad |F_c| = \frac{mv^2}{r} = m\omega^2 r$$

$$\vec{a}_c = -r\omega^2\hat{r} = -r\omega^2 = -\left(\frac{v^2}{r}\right)\hat{r} = -\left(\frac{v^2}{r^2}\right)\vec{r} \quad \text{or} \quad |a_c| = \frac{v^2}{r} = r\omega^2 = 4\pi^2 r T^{-2} = \frac{4\pi^2}{T^2} r$$

- Work done by centripetal force is zero.
- A centripetal force accelerates a body by changing the direction of the body's velocity without changing the body's speed.

- Centripetal and centrifugal forces form true action & reaction pair but they can't balance each other because they don't act on same body.

Condition	Centripetal force
Vehicle taking a turn on a level road	Frictional force exerted by the road on the tyres
A particle tied to a string and whirled in a horizontal circle	Tension in the string
Revolution of earth around the sun	Gravitational force exerted by the sun
A charged particle describing a circular path in a magnetic field	Magnetic force exerted by the agent that sets up the magnetic field

Centripetal acceleration	Tangential acceleration	Net acceleration	Type of motion
$a_c = 0$	$a_t = 0$	$a = 0$	Uniform translatory motion
$a_c = 0$	$a_t \neq 0$	$a = a_t$	Accelerated translatory motion
$a_c \neq 0$	$a_t = 0$	$a = a_c$	Uniform circular motion
$a_c \neq 0$	$a_t \neq 0$	$\vec{a} = \sqrt{a_c^2 + a_t^2}$	Non-uniform circular motion

For your information:

A stone that is stuck in a tyre of an automobile moving at highway speeds experiences a centripetal acceleration of about 2500 m/s^2 or 250 g.

MOTION IN A VERTICAL CIRCLE:

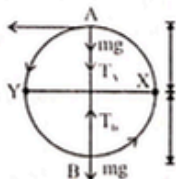
- When a body being tied to a string is whirled in a vertical plane, its speed is different at different points of the circular path.
- In such type of motion, the tension in the string and the centripetal force acting on the body go on varying continuously.
- At the highest point A, the tension in the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

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

$$\text{If } T_A = 0,$$

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

$$\text{or } v_A = \sqrt{gr}$$



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

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

- 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, $v_B = \sqrt{5gr}$

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

In Horizontal Circular motion the tension in the string at every point is remain same and equivalent of centripetal force

$$T = F_c = \frac{mv^2}{r}$$

Example: An object of mass of 2 kg rotates at constant speed in a horizontal circle of radius 5 m. The time for one complete revolution is 3 s. What is the magnitude of the resultant force acting on the object?

A) $\frac{4\pi^2}{9}$ N

B) $\frac{40\pi^2}{9}$ N

C) $\frac{100\pi^2}{9}$ N

D) $\frac{400\pi^2}{9}$ N

Solution: B) $F = mr\omega^2$

$$= mr \left(\frac{2\pi}{T} \right)^2$$

$$= 2 \times 5 \times \left(\frac{2\pi}{3} \right)^2 = \frac{40\pi^2}{9} \text{ N}$$

CRITICAL THINKING?

- A 500 kg car takes a round turn of radius 50 m with a velocity of 36 km/hr. The centripetal force is

A. 250 N	B. 750 N
C. 1200 N	D. 1000 N
- A stone is whirled in a vertical circle at the end of a string. When the stone is at the highest position the tension in the string is

A. Maximum	B. Zero
C. Equal to the weight of the stone	D. Less than the weight of the stone

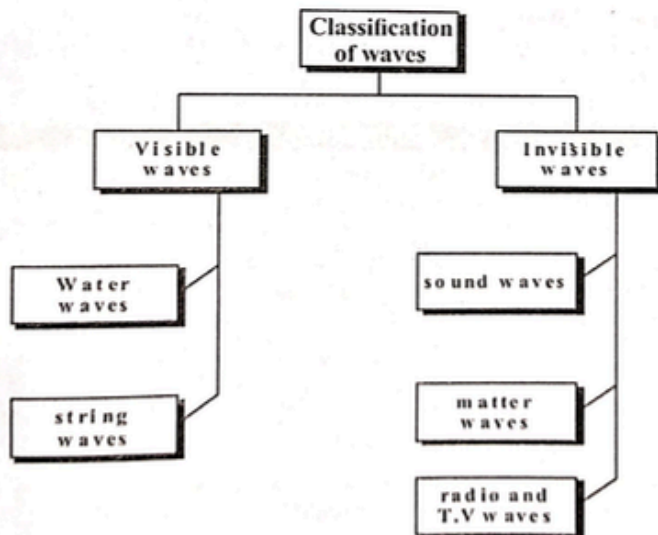
COURSE CONTENT

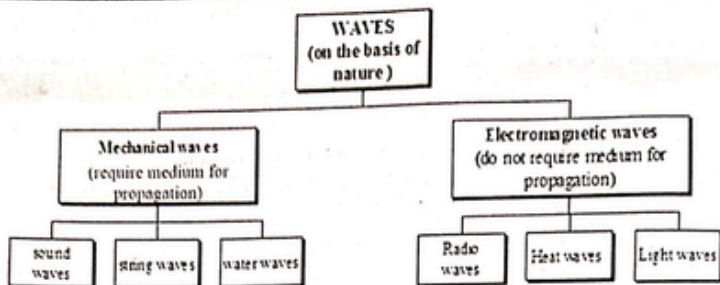
- Progressive wave (Crest, Trough, amplitude, wavelength, time period and frequency)
- Types of progressive waves (Transverse waves, Longitudinal waves)
- Periodic waves (Transverse periodic waves, Longitudinal periodic waves)
- Speed of sound in air
- Principle of superposition/ superposition of sound waves
- Stationary waves/ standing waves
- Stationary waves in a stretched string/fundamental frequency and harmonics
- Doppler effect
- Simple harmonic motion (SHM)
- Characteristics of simple harmonic motion
- Instantaneous displacement
- Amplitude
- Vibration
- Time period
- Frequency

Introduction

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

Classification of Waves





PROGRESSIVE WAVES

- Progressive wave or Traveling wave is that which propagates or distributes its pulses in space along specific direction. e.g.
 - (i) Waves in a string
 - (ii) Waves on a water surface

Types of Progressive Waves:

- On the basis of vibration of the particle, waves are classified in two types
 - (a) Transverse Waves
 - (b) Longitudinal Waves
 - (a) **Transverse Waves:**
 - The particles of the medium vibrate at right angles to the direction of propagation of the wave.
 - Crests and troughs are produced.
 - Transverse wave is not produced or possible in gases.
 - (b) **Longitudinal Waves:**
 - The particles of the medium vibrate along the direction of propagation of the wave.
 - Compressions and rarefactions are produced.
- Longitudinal waves are possible in all media i.e., solid, liquid and gas.

PERIODIC WAVES

- Periodic waves are those, which are repeated in regular interval of time.
- Periodic wave may be transverse or longitudinal.

Transverse Periodic waves:

- 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 in 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.

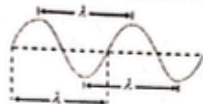
- In a transverse periodic wave time interval equal to time period, a particle in the wave travels a distance equal to wavelength.
- For all waves $v = \lambda f$.

Characteristics of Wave Motion:**(i) Frequency (f):**

The number of waves which pass a point per unit time is called the frequency of the wave motion.

(ii) Wavelength (λ):

- It is shortest distance between two consecutive points in the same phase.



- Distance travelled by the wave in one time period is known as wavelength
 - λ = Distance between the centers of two consecutive crests
 - λ = Distance between the centers of two consecutive troughs.
 - λ = Distance in which one trough and one crest are contained.
 - In longitudinal wave motion: λ = Distance between the centers of two consecutive compression.
 - In longitudinal wave motion: λ = Distance between the centers of two consecutive rarefaction
- (iii) Crest:**
A crest point on a wave is the maximum value of upward displacement within a cycle. A crest is a point on a surface wave where the displacement of the medium is at a maximum.
- (iv) Trough:**
A trough is the opposite of a crest, so the minimum or lowest point in a cycle.
- (v) Time Period (T):**
The time in which one wave cycle of a wave is passed through a certain point is called time period. It is represented by T. The unit of time period is second.
- (vi) Amplitude (A):**
The maximum displacement of a vibrating particle from mean position is called its amplitude.
- (vii) Wave Velocity (v):**
The distance traveled by the wave in one second is defined as its velocity.
- + The velocity of the particles of the medium is different from the velocity of the wave.
- + Wave velocity = frequency \times wavelength $v = \lambda f$

Do you know
The waves transport both energy and momentum in a medium.

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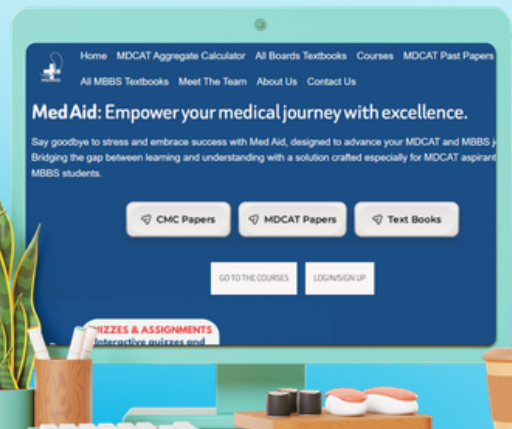
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Topic-4

- ✦ The relation $v = f\lambda$ holds good for any type of wave motion – transverse or longitudinal.
- ✦ When a given wave passes from one medium to the other, its frequency does not change.

$$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

- 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 $\frac{\lambda}{2}$ i.e. $(n + \frac{1}{2})\lambda = (2n + 1)\frac{\lambda}{2}$ are out phase to each other.

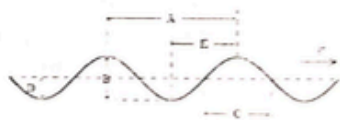
Example: A sound wave of frequency 400 Hz is travelling in a gas at a speed of 320 m s^{-1} . What is the phase difference between two points 0.2 m apart in the direction of travel?

- A. $\frac{\pi}{4}$ rad B. $\frac{\pi}{2}$ rad C. $\frac{2\pi}{5}$ rad D. $\frac{4\pi}{5}$ rad

Solution: B. As $v = f\lambda$ so $\lambda = \frac{v}{f} = \frac{320}{400} = 0.8 \text{ m}$, Phase difference = $\frac{2\pi x}{\lambda} = \frac{0.2}{0.8} \times 2\pi = \frac{\pi}{2}$ rad

CRITICAL THINKING

1. A sinusoidal wave is traveling toward the right as shown. Which letter correctly labels the amplitude of the wave?

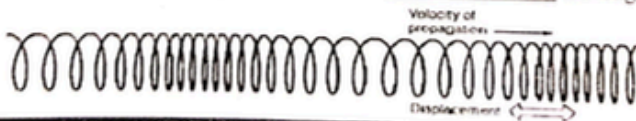


- A. A
C. B

- B. D
D. C

LONGITUDINAL PERIODIC WAVES

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



SPEED OF SOUND IN AIR

SOUND:

- A vibrating body produces sound waves ($\lambda = 1 \text{ m}$).
- Three things are essential for the detection of sound.
 - ✦ Vibrating body for production of sound
 - ✦ Medium for propagation of sound
 - ✦ Listener (ear) for the detection of sound

- Audible or sound waves: Range 20 Hz to 20 KHz. These are generated by vibrating bodies such as vocal cords, stretched strings or membrane.
- Infrasonic waves: Frequency lie below 20 Hz. Example: waves produced during earth quake, ocean waves etc.
- Longitudinal sound waves consist of compressions and rarefactions.
- Compression is a region where crowding of particles of medium is maximum.
- Rarefaction is region where crowding of particles of medium is minimum.
- Ultrasonic waves: Frequency greater than 20 KHz. Human ear cannot detect these waves.
- Mach number: It is the ratio of velocity of source to the velocity of sound

$$\text{Mach number} = \frac{\text{speed of source}}{\text{speed of sound}}$$

Gases (20°C)		Liquids (25°C)		Solids (20°C)	
Hydrogen	1284	Glycerin	1904	Iron	5960
Carbon Dioxide	259	Sea Water	1535	Pyrex Glass	5640
Oxygen	316	Water	1493	Aluminum	5100
Nitrogen	334	Mercury	1450	Lead	2160
Air	344	Methyl Alcohol	1103	Rubber	1550

For Your information:

- Sound is produced by vibrating objects.
- Sound waves are longitudinal waves having three dimensional propagations in air.
- Sound waves produce Reflection, Refraction, Diffraction, Interference but not polarization because sound waves are longitudinal.

Speed of sound in air:

- **Newton's Formula:**

Newton proved that when longitudinal waves (sound) move in elastic medium, the velocity is given by

$$v = \sqrt{\frac{E}{\rho}} \quad \text{Where } E \text{ is the modulus of elasticity of the medium and } \rho \text{ is its density.}$$

Note: Wave velocity in a medium is fixed. Wave velocity is a material constant. It does not depend on wavelength, frequency and intensity.

- **For Solids:**

Modulus of elasticity

$E = \text{Young's modulus of elasticity} = Y$

$$\therefore v = \sqrt{\frac{Y}{\rho}}$$

- **For liquids:**

Modulus of elasticity

$E = \text{Bulk modulus of elasticity} = B$

$$\therefore v = \sqrt{\frac{B}{\rho}}$$

- For gases:

For a gaseous medium, Newton assumed that the propagation of longitudinal wave is an isothermal process (temperature remains constant). In this case, modulus of elasticity

$E = \text{Pressure of the gas} = P$

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

Note:

- (i) The experimental results did not confirm to Newton's assumption. Laplace corrected the formula by arguing that sound waves travel adiabatically. Hence,

$$v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\frac{\gamma KT}{m}}$$

where, T is absolute temperature of the gas, M is its molecular weight and R is universal gas constant.

$k = \frac{R}{N}$ = Boltzmann constant, N = Avogadro number

$m = \frac{M}{N}$ = Mass of one molecule

- (ii) Velocity of longitudinal wave in: **solid medium > liquid medium > gaseous medium**

For your information:

Vibrating vocal cords produce the human voice. The ear can detect very tiny pressure variations.

CRITICAL CONCEPT!

When explosion due to fusion reactions take place on the surface of sun then why we cannot hear their sound.

Effects on the speed of sound in a Gas:

- Effect of pressure:**

With the change of pressure, the velocity of sound in a gas remains unchanged, that is, there is no effect of pressure on the velocity of sound in gas.

- Effect of temperature:**

$v \propto \sqrt{T}$. Thus, the velocity of sound is directly proportional to the square root of the absolute temperature, i.e.,

$$\frac{v_t}{v_o} = \sqrt{\frac{T_t}{T_o}} = \sqrt{\frac{273+t}{273}}$$

$$v_t = v_o \left(1 + \frac{t}{273}\right)^{\frac{1}{2}} \quad \text{or} \quad v_t = v_o + 0.61 t$$

Effect of moisture:

The presence of moisture in the air reduces the resultant density of air. The net result is that the speed of sound increases with humidity. Hence the velocity of sound in damp air is greater than its value in dry air.

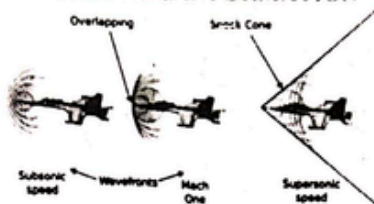
Effect of density:

The speed of sound in a gas varies inversely as the square of the density of gas. $v \propto \frac{1}{\sqrt{\rho}}$

(At the same temperature and pressure of gases)

Effect of Wind:

If the air carrying sound waves, is itself moving i.e. there is wind. The speed of sound in the direction of wind relative to the ground is $(v+v_w)$ while against the wind is $(v-v_w)$, where v_w is the speed of wind and v is the speed of sound.

INTERESTING INFORMATION**For your Information:**

- The speed of sound is higher in liquids and solids than it is in gases.
- The speed of sound in air increases 0.6 ms^{-1} for each 1°C increases.
- If the speed of a body in air exceeds the speed of sound, then it is called supersonic. Such a body leaves behind it a conical region of disturbance which spread continuously. Such a disturbance is called "shock wave". These waves may make cracks in window panels.

CRITICAL THINKING ?

- The speed of sound in air is a function of

A. Wavelength	B. Frequency
C. Temperature	D. Amplitude
- The velocity of sound in air would become double than its velocity at 0°C at temperature

A. 313°C	B. 586°C
C. 819°C	D. 1172°C

PRINCIPLE OF SUPERPOSITION / SUPERPOSITION OF SOUND WAVES

- If two or more waves propagate simultaneously in a medium, then the resultant displacement is given by the vector sum of displacement due to individual waves. If the displacement given by the various waves to the particle are $\vec{y}_1 + \vec{y}_2 + \vec{y}_3 + \dots + \vec{y}_n$, then the resultant displacement of the particle is $\vec{y} = \vec{y}_1 + \vec{y}_2 + \vec{y}_3 + \dots + \vec{y}_n$
- Different phenomenon due to principle of superposition are

(a) Interference	(b) Beats	(c) Stationary waves
------------------	-----------	----------------------

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 $n = 0, +1, +2, \dots$

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

Condition for Destructive Interference:

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

- 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.

Beats:

When two sound waves of slightly different frequencies, travelling in a medium along the same direction, superimpose on each other, the intensity of the resultant sound at a particular position rises and falls regularly with time. This phenomenon of regular variation in intensity of sound with time at a particular position is called beats.

- Beat frequency:**

The number of beats produced per second is called beat frequency.

$$f = f_1 - f_2$$

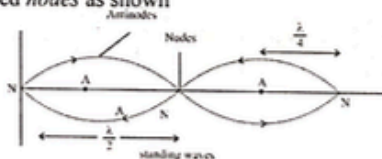
- Beat period:**

The time interval between two successive beats (i.e. two successive maxima of sound) is called beat period.

$$\text{Beat period: } T = \frac{1}{\text{beat frequency}} = \frac{1}{f_1 - f_2}$$

STATIONARY WAVES / STANDING WAVES**Stationary Waves:**

- Superposition of two identical waves traveling opposite to each other in the same medium simultaneously, gives rise to stationary or standing waves
- Points of constructive interference are called *antinodes* while points of destructive interference are called *nodes* as shown



- Amplitude is maximum at antinodes and minimum (zero) at nodes.
- All the particles in one particular segment vibrate in the same phase. Particles in two consecutive segments differ in phase by 180°
- All the particles except those at nodes, execute simple harmonic motion about their mean position with the same time period.
- Velocity of particles while crossing mean position varies from maximum at antinodes to 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 $\lambda/4$.

For your information:

The speed of a wave along a stretched ideal string depends only on the tension and linear density of the string and not on the frequency of the wave.

Example: Progressive waves of frequency 300 Hz are superimposed to produce a system of stationary waves in which adjacent nodes are 1.5 m apart. What is the speed of the progressive waves?

- A. 100 m s^{-1} B. 200 m s^{-1} C. 450 m s^{-1} D. 900 m s^{-1}

Solution: D. The distance 1.5 m corresponds to half of a wavelength, λ . The wavelength is thus given by $\lambda = 2(1.5) = 3.0 \text{ m}$

The speed of the wave, $v = f\lambda = (300)(3) = 900 \text{ m s}^{-1}$

CRITICAL THINKING?

4. A rope of length 5 m is stretched to a tension of 80 N. If its mass is 1 kg, at what speed would a 10 Hz transverse wave travel down the string?

- A. 2 m/s B. 5 m/s
C. 20 m/s D. 50 m/s

STATIONARY WAVES IN A STRETCHED STRING/FUNDAMENTAL FREQUENCY AND HARMONICS

- The vibrations of a thin, long and perfectly elastic string are transverse stationary.
- On both the ends of string there are nodes, and an antinode is there in the middle.

- The speed of transverse wave in a stretched string is given by $v = \sqrt{\frac{T}{\mu}}$

Where T and μ are respectively the tension and mass per unit length of the string ($\mu = m/L$).

Modes of vibration in a stretched string are as under

- If a string of length l vibrates in one loop then $\lambda_1 = 2l$

and frequency $f_1 = \frac{v}{2l} = \frac{1}{2l} \sqrt{\frac{T}{m}}$. This frequency is called the fundamental note or first harmonic.

- If the string vibrates in two loops, then $\lambda = l$ and

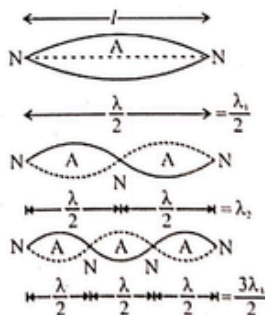
$f_2 = \frac{v}{l} = 2f_1$. This frequency is called the first overtone or second harmonic.

- If the string vibrates in three loops, then

$$\frac{3\lambda_3}{2} = l \rightarrow \lambda_3 = \frac{2l}{3}$$

$\therefore f_3 = \frac{3v}{2l} = 3f_1$. This frequency is called the second overtone or third harmonic.

- Both the odd and even harmonics are emitted from a stretched string. That is $f_n = nf_1$, where $n = 1, 2, 3, \dots$



For your information:

The energy emitted from sound produced by a crowd of 60,000 at a football match is enough to warm a cup of tea.

Example: The frequency of the fundamental mode of transverse vibration of a stretched wire 100 mm long is 256 Hz. When the wire is shortened to 400 mm at the same tension, what is the fundamental frequency?

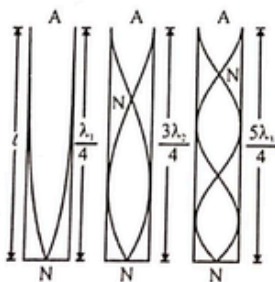
- A. 162 Hz B. 312 Hz C. 416 Hz D. 640 Hz

Solution: D. The frequency of the fundamental mode of a stretched wire is $f = \frac{1}{2l} \sqrt{\frac{T}{m}}$

$$f \propto \frac{1}{l} \Rightarrow \frac{f_2}{f_1} = \frac{l_1}{l_2} \Rightarrow \frac{f_2}{256} = \frac{1000}{400} \Rightarrow f = 640 \text{ Hz}$$

STATIONARY WAVES IN AIR COLUMNS

- An organ pipe is a pipe that sets in vibration the air enclosed in it when the air is blown into it. As a result, sound is produced in it.
- Organ pipes are of two types – closed end organ pipe and open end organ pipe.
- An open end organ pipe has both its ends open.
- A closed end organ Pipe has one of its ends closed and the other open.
- In a closed end pipe a node is always formed at the closed end and an antinode is formed at the open end.
- Longitudinal stationary waves are formed in an organ pipe.
- Various stages of resonance in a **CLOSED END** organ pipe are represented in the following diagrams.



- If the length of the pipe $l = \frac{\lambda_1}{4}$ then $\lambda_1 = 4l$, \therefore Frequency, $f_1 = \frac{v}{\lambda_1} = \frac{v}{4l}$

This frequency is called fundamental frequency or fundamental note or first harmonic.

- If $l = \frac{3\lambda_2}{4}$ then $\lambda_2 = \frac{4l}{3}$, \therefore Frequency, $f_2 = \frac{v}{\lambda_2} = \frac{3v}{4l} = 3f_1$

This frequency is called third harmonic or first overtone.

- If $l = \frac{5\lambda_3}{4}$ then $\lambda_3 = \frac{4l}{5}$, \therefore Frequency, $f_3 = \frac{v}{\lambda_3} = \frac{5v}{4l} = 5f_1$

This frequency is called fifth harmonic or second overtone.

Only odd harmonics can be produced in a closed end organ pipe. That is $f_n = (2n - 1)f_1$ where $n = 1, 3, 5, \dots$

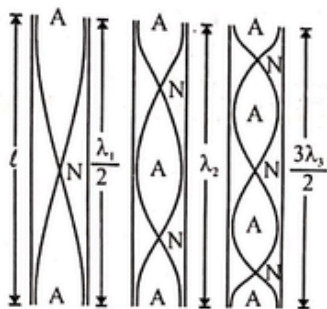
Longitudinal stationary waves are formed in an OPEN END ORGAN PIPE too.

The antinodes are formed at both the ends of an open pipe.

Various stages of resonance in an open organ pipe have been represented in the following diagrams

CRITICAL CONCEPT!

Under what principle a sound is produced in a flute?



- If $l = \frac{\lambda_1}{2}$ then $\lambda_1 = 2l$, \therefore Frequency, $f_1 = \frac{v}{\lambda_1} = \frac{v}{2l}$

This frequency is called the fundamental frequency or the fundamental note or the first harmonic.

- If $l = \lambda_2$ then $f_2 = \frac{v}{\lambda_2} = \frac{v}{l} = 2f_1$

This frequency is called the second harmonic or first overtone.

- If $l = \frac{3\lambda_3}{2}$ then $\lambda_3 = \frac{2l}{3}$, \therefore Frequency, $f_3 = \frac{v}{\lambda_3} = \frac{3v}{2l} = 3f_1$

This frequency is called the third harmonic or second overtone are produced in an open-end organ pipe. That is $f_n = nf_1$, where $n = 1, 2, 3, \dots$

- The sound emitted by an open-end organ pipe is musical.

No. of harmonics in open pipe = 2 x No. of harmonics in closed pipe

Example: 2nd overtone of an open organ pipe resonates with 3rd harmonics of a closed organ pipe. The ratio of their length will be

- A. $\frac{2}{1}$ B. $\frac{1}{2}$ C. $\frac{6}{5}$ D. $\frac{5}{6}$

Solution: A. $\frac{L_1}{L_2} = \frac{3\lambda/2}{3\lambda/4} = \frac{2}{1}$

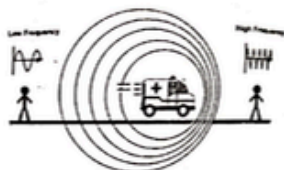
CRITICAL THINKING?

5. The ratio of the fundamental frequency of an open ended pipe to a pipe whose one end is closed is
- A. 1:2
B. 2:1
C. 1:1
D. 1:4
6. Which one is the correct relation for fundamental frequency of open and closed pipe?
- A. $f_{\text{open}} = 2 f_{\text{closed}}$
B. $f_{\text{closed}} = 2 f_{\text{open}}$
C. $f_{\text{open}} = f_{\text{closed}}$
D. $f_{\text{open}} = 1/ f_{\text{closed}}$

DOPPLER'S EFFECT

Doppler Effect (Frequency Shift)

- 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' is given as;

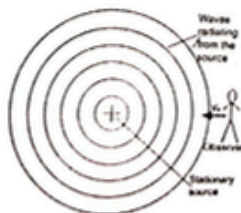


$$f' = \left(\frac{v}{v - u_s} \right) f \quad f' > f \text{ or } \lambda' = \left(\frac{v - u_s}{v} \right) \lambda \quad \lambda' < \lambda$$

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

$$f' = \left(\frac{v}{v + u_s} \right) f \quad f' < f \text{ or } \lambda' = \left(\frac{v + u_s}{v} \right) \lambda \quad \lambda' > \lambda$$

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



$$f' = \left(\frac{v + u_o}{v} \right) f \quad f' > f \text{ or } \lambda' = \left(\frac{v}{v + u_o} \right) \lambda \quad \lambda' < \lambda$$

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



$$f' = \left(\frac{v - u_o}{v} \right) f \quad f' < f \quad \text{or} \quad \lambda' = \left(\frac{v}{v - u_o} \right) \lambda \quad \lambda' > \lambda$$

- When both source and observer move towards each other.

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

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

- When both source and observer move away from each other.

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

Applications of Doppler's effect

- Ships and submarine (sonar devices)
- Bats (for traveling)
- Radar (for detection)
- Determining velocity of a star w.r.t earth
- 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.

CRITICAL CONCEPT!

Can you apply Doppler's effect for light wave and source of light?



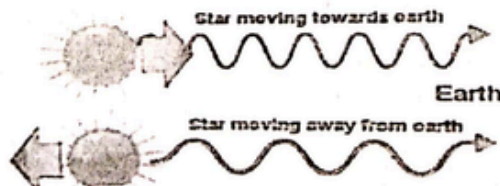
Star is moving towards Earth: Blue Shift



Star is at rest: No Change



Star is moving away from Earth: Red Shift



- Frequency is number of vibrations per second and denoted by f $f = \frac{1}{T}$

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

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

Example:

A mass connected to a spring makes 15 vibrations in 45 second. Calculate its period and frequency.

Solution:

Number of vibration = 15

Time for 15 vibration = 45 s

$T = ?$

$f = ?$

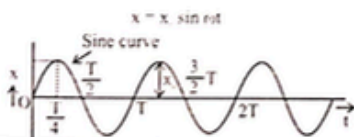
$$T = \frac{\text{given time}}{\text{No. of vibs.}} = \frac{45}{15} = 3\text{ s}$$

$$f = \frac{1}{T} = \frac{1}{3} = 0.333 \text{ Hz}$$

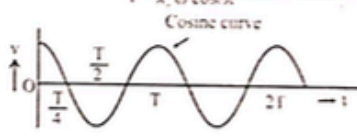
SIMPLE HARMONIC MOTION AND REFERENCE CIRCLE

- Motion of projection of a body moving in a circle, on the diameter with constant speed is S.H.M
- Instantaneous acceleration is given as; $a = -\omega^2 x$
- Time period of projection is given as; $T = \frac{2\pi}{\omega}$
- Instantaneous Displacement: $x = x_0 \sin \omega t$
- Speed of projection is given as; $v = \omega \sqrt{x_0^2 - x^2}$
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.
- 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

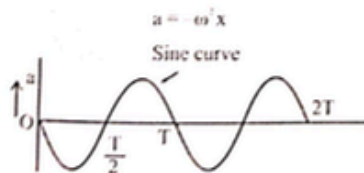
DISPLACEMENT-TIME GRAPH



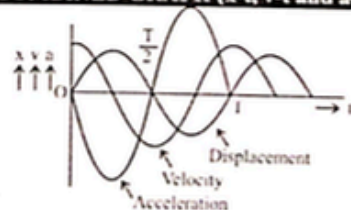
VELOCITY-TIME GRAPH



ACCELERATION-TIME GRAPH



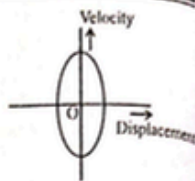
COMBINED GRAPH (x-t, v-t and a-t)



- Velocity-displacement graph (v-x): Graph between velocity and displacement in case of SHM is always ellipse.

$$v = \omega\sqrt{x_0^2 - x^2} \quad \text{or} \quad v^2 = \omega^2(x_0^2 - x^2) = \omega^2x_0^2 - \omega^2x^2$$

$$v^2 + \omega^2x^2 = \omega^2x_0^2 \quad \text{or} \quad \frac{v^2}{(\omega x_0)^2} + \frac{x^2}{x_0^2} = 1$$



FOR YOUR INFORMATION

$\omega = \frac{2\pi}{T}$

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}

Example: A simple harmonic oscillator has a time period of 10 seconds. Which equation relates its acceleration a and displacement x ?

A. $a = -10x$

B. $a = -(20\pi)x$

C. $a = -(20\pi)^2 x$

D. $a = -(2\pi/10)^2 x$

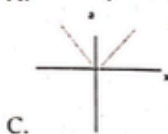
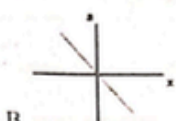
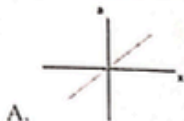
Solution: D. $a = -\omega^2 x$ and $\omega = \frac{2\pi}{T}$

Where T is the period.

$$\therefore a = \left(\frac{2\pi}{10}\right)^2 x$$

CRITICAL THINKING?

9. What is constant in S.H.M?
 A. Restoring force
 B. Kinetic energy
 C. P.E
 D. Periodic time
10. Which one is the correct graph between acceleration 'a' and displacement 'x' for SHM?



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;

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

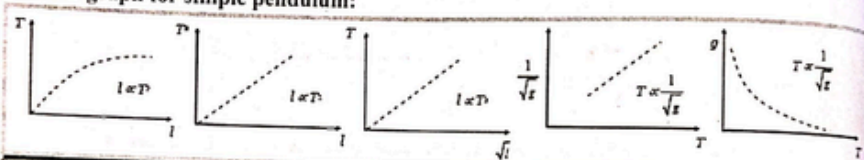
- If amplitude of simple pendulum is not small then, it has non-S.H.M as $a = -g \sin\theta$ and we know that $\sin\theta = \theta$ only when θ is small.
- A second pendulum has following characteristics;

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

CRITICAL CONCEPT!

Every vibrating body produces a sound. Does a simple pendulum also produce a sound?

Various graph for simple pendulum:



Pendulum suspended in a lift: If the pendulum is suspended in a lift ascending up with uniform

acceleration 'a' then its time-period is $T = 2\pi\sqrt{\frac{l}{g+a}}$

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

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

- A second pendulum has following characteristics:

Spring Pendulum:

A point mass suspended from a mass less spring or placed on a frictionless horizontal plane attached with spring constitutes a linear harmonic spring pendulum

$$T\sqrt{\frac{\text{inertia}}{\text{spring constant}}} = 2\pi\sqrt{\frac{m}{k}}$$

Oscillation of a Mass Attached to a Spring:

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

$$\begin{aligned} v_{\text{inst}} &= \omega\sqrt{x_0^2 - x^2} \\ v_{\text{inst}} &= \sqrt{\frac{k}{m}(x_0^2 - x^2)} \quad \text{as } \omega = \sqrt{\frac{k}{m}} \\ &= \sqrt{\frac{k}{m}}x_0\sqrt{1 - \frac{x^2}{x_0^2}} \\ &= v_{\text{max}}\sqrt{1 - \frac{x^2}{x_0^2}} \end{aligned}$$

- Oscillator has maximum speed at the mean position so put $x = 0$

$$v_{\max} = \omega x_0 \quad \text{OR} \quad v_{\max} = v_0 = x_0 \sqrt{\frac{k}{m}}$$

- Time period $T = 2\pi \sqrt{\frac{m}{k}}$ m is the mass of the body attached and k is

$$\text{force constant and frequency } f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

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

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

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

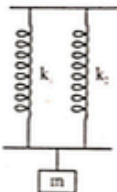
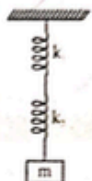
Spring in series: Equivalent force constant of springs

$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} \quad \text{or} \quad k = \frac{k_1 k_2}{k_1 + k_2} \quad \text{and time period}$$

$$T = 2\pi \sqrt{\frac{m(k_1 + k_2)}{k_1 k_2}}$$

Springs in parallel: Equivalent force constant of springs $k = k_1 + k_2$ and

$$\text{time period } T = 2\pi \sqrt{\frac{m}{k_1 + k_2}}$$



- Example:** The bob of a simple pendulum is a spherical hollow ball filled with water. A plugged hole near the bottom of the oscillating bob gets suddenly unplugged. During observation, till water is coming out, the time period of oscillation would
- First decrease and then increase to the original value.
 - First increase and then decrease to the original value.
 - Increase towards a saturation value.
 - Remain unchanged.

Solution: B. Centre of mass of combination of liquid and hollow portion (at position l), first goes down (to $l + \Delta l$) and when total water is drained out, center of mass regains its original position (to l)

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

$\therefore T$ first increases and then decreases to original value.

For your Information:

If a pendulum is shifted from Karachi to Quetta, then its time period will be increased.

TOPIC-5 THERMODYNAMICS

COURSE CONTENT

- Thermal Energy is transferred from the region of higher temperature to the region of lower temperature
- First law of thermodynamics
- Specific heat and molar specific heat/ specific heat capacity.
- Relation $C_p - C_v = R$
- Internal Energy
- Heat and Work

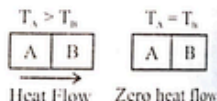
TEMPERATURE

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 from 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 caloric.
- 4.2 Joule = 1 caloric

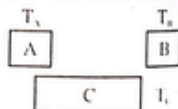
Thermal Equilibrium: Objects A and B are in contact. If heat flows from A to B, then A is at a higher temperature than B. When the heat flow from A to B is zero, the two objects are in thermal equilibrium.



Zerotherm 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,

$$T_A = T_C \quad \text{and} \quad T_B = T_C \quad \text{then,} \quad T_A = T_B$$

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.



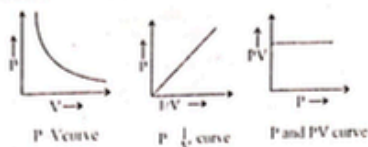
For Your Information:

- A thermodynamics system which is surrounded by a distinct boundary.



- An open system which transfer both energy and matter.
- A closed system which transfers only energy.
- An isolated system which transfers neither energy nor matter.

Different Thermodynamic Process and Relative: Thermodynamics Process



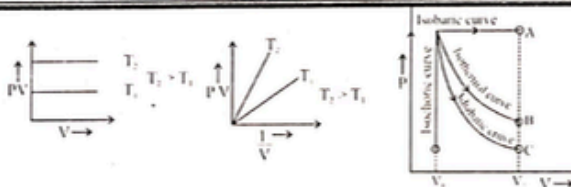
CRITICAL THINKING

2. Four curves A, B, C and D are drawn in the adjoining figure for a given amount of gas. The curves which represent adiabatic and isothermal changes are.



A. C and D respectively
C. D and C respectively

B. A and B respectively
D. B and A respectively



SPECIFIC HEAT AND MOLAR SPECIFIC HEAT/SPECIFIC HEAT CAPACITY.

- Amount of heat required to raise the temperature of a substance through 1 K is called *heat capacity*, denoted by C.
 $Q = C \Delta T$

Specific Heat: The heat required to increase the temperature of unit mass of substance by 1°C is called the specific heat of the substance. $Q = mc\Delta T$ or $c = \frac{Q}{m\Delta T}$. Its unit is $\text{J kg}^{-1} \text{K}^{-1}$.

Molar Specific heat:

The amount of heat energy required to raise the temperature of one mole of the gas through 1K.

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

Molar Specific heat at Constant Volume

- Molar specific heat at constant volume is the amount of heat required to raise the temperature of one mole of the gas through 1K keeping volume constant.

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

Molar Specific Heats of Various Gases

Gas	C_p	C_v	$C_p - C_v$	γ
Monoatomic gases				
He	21	13	8.33	1.67
Ar	21	13	8.33	1.67
Ne	21	13	8.12	1.64
Kr	21	12	8.49	1.69
Diatomic gases				
H ₂	29	20	8.33	1.41
N ₂	29	21	8.33	1.4
O ₂	29	21	8.33	1.4
CO ₂	29	21	8.33	1.4
Cl ₂	35	26	8.96	1.4
Polyatomic gases				
CO	37	29	8.5	1.3
SO ₂	40	31	9	1.29
H ₂ O	35	27	8.37	1.3
CH ₄	36	27	8.41	1.31

Specific Heat at Constant Pressure:

Molar specific heat at constant pressure is the amount of heat required to raise the temperature of one mole of the gas through 1K keeping pressure constant.

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

Relation $C_p - C_v = R$:

- $\Delta Q_v = n C_v \Delta T$ (Heat supplied at constant volume).
- $\Delta Q_p = n C_p \Delta T$ (Heat supplied at constant pressure).

$$C_p - C_v = R.$$

$$\frac{C_p}{C_v} = \gamma$$

- As $C_p - C_v = R$ is only applicable for $n = 1$.
- For n number of moles $C_p - C_v = nR$

When different moles of different gases are mixed, mean of γ is not taken, but mean of C_p and C_v may be taken

$$(C_v)_{\text{mean}} = \frac{n_1 C_{v1} + n_2 C_{v2}}{n_1 + n_2}$$

$$(C_p)_{\text{mean}} = (C_v)_{\text{mean}} + R \Rightarrow \gamma_{\text{mean}} = \frac{(C_p)_{\text{mean}}}{(C_v)_{\text{mean}}}$$

Gamma mean is directly found by

$$\frac{n_1 + n_2}{\gamma_{\text{mean}} - 1} = \frac{n_1}{\gamma_1 - 1} + \frac{n_2}{\gamma_2 - 1}$$

YPES OF GAS	C_v	C_p	$\gamma = \frac{C_p}{C_v}$
Monoatomic	$\frac{3}{2}R$	$\frac{5}{2}R$	1.67
Diatomic	$\frac{5}{2}R$	$\frac{7}{2}R$	1.40
Polyatomic	$\frac{7}{2}R$	$\frac{9}{2}R$	1.29

Example: In an experiment to determine the specific heat capacity of a liquid by an electrical method, a student obtained the following results.

Mass of liquid heated	1.5 kg
Initial liquid temperature	300 K
Final liquid temperature	357 K
Electrical power of heater	1.0 kW
Time of heating	180 s

What is the specific heat capacity of the liquid?

A. $2.1 \text{ J kg}^{-1} \text{ K}^{-1}$

C. $18 \text{ J kg}^{-1} \text{ K}^{-1}$

B. $1800 \text{ J kg}^{-1} \text{ K}^{-1}$

D. $2100 \text{ J kg}^{-1} \text{ K}^{-1}$

Solution: D. The specific heat capacity, $c = \frac{Q}{m\Delta T}$

$$= \frac{\text{Power} \times \text{time}}{\text{mass} \times \Delta T} = \frac{(1.0 \times 10^3)(180)}{(1.5)(357 - 300)} = 2100 \text{ J kg}^{-1} \text{ K}^{-1}$$

CRITICAL THINKING?

3. Out of following whose specific heat is maximum?
 A. lead
 B. Brass
 C. Glass
 D. Iron
4. If $C_p = 56 \text{ kJ}$ and $C_v = 28 \text{ kJ}$ then $n = ?$
 A. 2.36
 B. 3.36
 C. 4.56
 D. 8.16

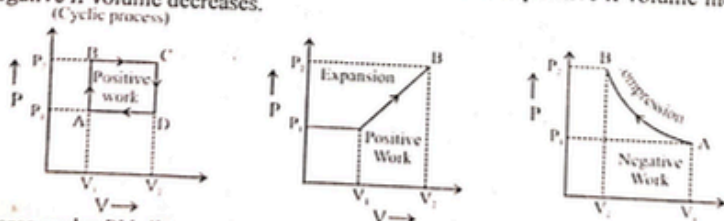
INTERNAL ENERGY

Internal Energy

- The energy possessed by a system due to molecular motion and configuration is considered as its internal energy.
- Internal energy of a system = Kinetic energy of its constituents molecules + Potential energy of its constituents molecules.
- Internal energy is a state function which depends on pressure, temperature, volume etc, of the system.
- The change in the internal energy of a system depends only on initial and final states of the system and not on the path followed.
- For an ideal gas the potential energy of the molecules is zero. Here internal energy = Kinetic energy of molecules and it depends on temperature.

HEAT AND WORK

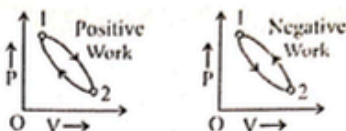
- "Heat is a form of energy which flows from the hotter body to the colder body till the temperatures of the two bodies become equal".
- Work can be defined as the energy that is transferred one body to the other owing to a force that acts between them. The amount of work done by a system as it expands 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.



- 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.

Cyclic Process:

A cyclic process is one in which the thermodynamic variables periodically return to their original values. In other words, the initial and final states of the system coincide. The work done by a cyclic process is equal to the area enclosed by the loop.



Cyclic Processes

Positive work:

If the cycle is traversed in the clockwise sense.

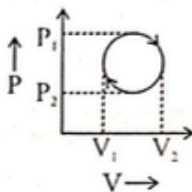
Negative work:

If the cycle is traversed in the anticlockwise sense.

If a cyclic process is represented by a circle on the P-V diagram as shown in the fig, then the work done is given

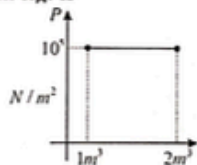
by $W = \frac{\pi}{4} (P_2 - P_1)(V_2 - V_1)$. The change in internal energy

of a cycle process is zero $\Delta U = 0$. Therefore, from First Law, we may conclude $Q = W$.



CRITICAL THINKING

5. The work done in fig: is



- A. $3 \times 10^5 \text{ J}$
C. 10^5 J

- B. $2 \times 10^5 \text{ J}$
D. Zero



COURSE CONTENT

- Coulomb's Law (Coulomb's Law in material media)
- Electric field and its intensity
- Application of Gauss's law (Electric field intensity due to an infinite sheet of charge, Electric field intensity between two oppositely charged parallel plates)
- Electric potential
- Capacitor (Capacitance of a capacitor and its unit)
- Capacitance of a parallel plate capacitor
- Energy Stored in a Capacitor
- Charging and Discharging a Capacitor

COULOMB'S LAW (COULOMB'S LAW IN MATERIAL MEDIA)

If two stationary point charges q_1 and q_2 are kept at a distance r , then it is found that force of attraction or repulsion between them is

$$F \propto \frac{q_1 q_2}{r^2} \quad \text{i.e.,} \quad F = k \frac{q_1 q_2}{r^2}$$

Vector form of Coulomb's Law

Vector form of Coulomb's law is

$$\vec{F}_{12} = k \frac{q_1 q_2}{r^2} \hat{r}_{12}, \quad \vec{F}_{21} = k \frac{q_1 q_2}{r^2} \hat{r}_{21}$$

Where \hat{r}_{12} is the unit vector from first charge to second charge along the line joining the two charges and vice versa?

Note: Constant "k" depends upon system of units and medium between two charges.

(i) Effect of Units:

- In C.G.S. system for air $k = 1$, $F = \frac{q_1 q_2}{r^2}$ dyne.
- In S.I. for air $k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$, $F = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r^2}$ Newton ($1\text{N} = 10^5 \text{ dyne}$)

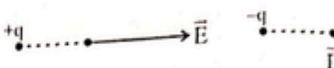
(ii) Coulombs Law in Material Media

- When a dielectric medium or specific inductive capacity (SIC) of the medium, is completely filled in between charges rearrangement of the charges inside the dielectric medium takes place and the force between the same two charges decreases by a factor of ϵ_r known as dielectric constant is also called relative permittivity ϵ_r of the medium.

$$\text{Hence in the presence of medium } F_m = \frac{1}{4\pi\epsilon_0\epsilon_r} \cdot \frac{q_1 q_2}{r^2} \Rightarrow \epsilon_r = \frac{F_{air}}{F_m}$$

Direction of electric field:

Electric field (intensity) \vec{E} is a vector quantity. Electric field due to a positive charge is always away from the charge and that due to a negative charge is always towards the charge.

**Relation between electric force and electric field:**

In an electric field \vec{E} a charge (q) experiences a force $F = qE$. If charge is positive then force is directed in the direction of field while if charge is negative force acts on it in the opposite direction of field.



- The electric field of a continuous charge distribution at some point.

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

Where q is the charge on one element of the charge distribution r is the distance from the element to the point under consideration, \hat{r} is the unit vector directed from the position of eliminated charge towards the point where electric field is to be found out?

CRITICAL CONCEPT!

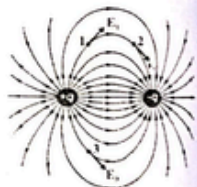
Does an electric field exist in empty space?

Electric field lines:

- 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;

- Originate from positive charge.
- End on negative charge.
- Do not intersect
- Contract longitudinally.
- Repel transversely.
- Tangent drawn to electric lines gives the direction of electric intensity
- Electric field is stronger where the electric lines are closely packed

**Equipotential Surface**

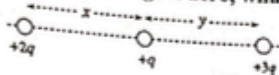
- If every point of a surface is at same potential, then it is said to be an equipotential surface.
- The direction of electric field is perpendicular to the equipotential surfaces or lines of force.
- The equipotential surfaces produced by a point charge or a spherically charge distribution are a family of concentric spheres.
- Equipotential surfaces can never cross each other.
- Work done in moving any charge over these surfaces is zero.

For Your information:

- There is no electric field inside the conductor.

CRITICAL THINKING?

3. A metallic charged sphere is placed in uniform electric field E , the electric field inside the sphere will be
 A. E B. Less than E
 C. Greater than E D. Zero
4. The figure below shows three-point charges, all positive. If the net electric force on the center charge is zero, what is the value of $\frac{y}{x}$?



A. $\frac{4}{9}y$
 C. $\sqrt{\frac{3}{2}}y$

B. $\sqrt{\frac{2}{3}}y$
 D. $\frac{3}{2}y$

$$E = -\frac{\Delta V}{\Delta d}$$
 TO CALCULATE THE FIELD STRENGTH

We can relate electric potential difference and electric field intensity by following relation: $E = -\frac{\Delta V}{\Delta r}$

Where negative shows that \vec{E} is along decreasing potential.

- (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. $\frac{1N}{1C} = \frac{1V}{1m}$

Example: A thunder-cloud whose base is 500 m above the ground. The potential difference between the base of the cloud and the-ground is 200 MV. A raindrop with a charge of 4.0×10^{-12} C is in the region between the cloud and the ground. What is the electrical force on the raindrop?

- A. 1.6×10^{-6} N B. 8.0×10^{-4} N C. 1.6×10^{-3} N D. 0.40 N

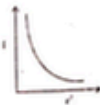
Solution: A. $F = qE = q\left(\frac{V}{d}\right) = (4.0 \times 10^{-12})\left(\frac{200 \times 10^6}{500}\right) = 1.6 \times 10^{-9}$ N

$$E = \frac{Q}{4\pi\epsilon_0 r^2}$$
 FOR THE FIELD STRENGTH

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

$$E \propto \frac{1}{r^2} \text{ (Inverse square law)} \Rightarrow \frac{E_1}{E_2} = \left(\frac{r_2}{r_1}\right)^2$$

Graph:



CRITICAL CONCEPT

- What will be the value of electric potential when a positive charged particle moves in the direction of electric field?
- What will be the work done on the charged particle when it is displaced between two points which have same potential?

Example: A conducting hollow sphere of radius 0.1 m is given a charge of 10 μC . The electric potential on the surface of sphere will be

A. Zero

B. $3 \times 10^5 \text{V}$ C. $9 \times 10^5 \text{V}$ D. $9 \times 10^9 \text{V}$

Solution: C. $V_{\text{surface}} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r} = \frac{9 \times 10^9 \times 10 \times 10^{-6}}{10^{-1}} = 9 \times 10^5 \text{V}$

- **Absolute potential** at a point due to collection of point charges is given as;

$$V = \frac{1}{4\pi\epsilon_0} \sum_{i=1}^n \frac{q_i}{r_i}$$
- ECG records the voltage between points on human skin generated by electrical process in the heart while EEG records that by brain.

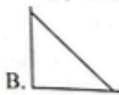
Electron Volt

The amount of energy acquired or lost by an electron as it traverses a potential difference of one volt.

- $1\text{eV} = 1.6 \times 10^{-19} \text{J}$ and $1\text{J} = 6.25 \times 10^{18} \text{eV}$
It is the unit of energy specially used for atomic particles

CRITICAL THINKING

6. The variation of electric potential due to a point charge with distance is represented by the graph (where V along y-axis and r along x-axis)

**CAPACITOR (CAPACITANCE OF A CAPACITOR AND ITS UNIT)**

Capacitor is a device used for storing electric charge and electrical energy.

- Charge stored by capacitor is given as; $Q = CV$ Where C is capacitance of capacitor
- **Capacitance is defined as** Ability of a capacitor to store charge. OR
"The ratio of charge stored to the potential difference between plates of capacitor."

Mathematically, $C = \frac{Q}{V}$

Topic-6

- SI unit of capacitance is Farad.
- **1 Farad** It 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

$$1F = 1C/1V$$

CAPACITANCE OF PARALLEL PLATE CAPACITOR

- Capacitance of parallel plate capacitor with air between its plates is given as;

$$C_{vac} = \epsilon_0 \frac{A}{d}$$

The above expression shows that-

- As we increase the surface 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 a parallel plate capacitor with dielectric between its plate is given as;

$$C_{med} = \epsilon_r \epsilon_0 \frac{A}{d} = \epsilon_r C_{vac} \quad \text{so} \quad C_{med} > C_{vac}$$

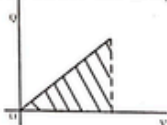
Dielectric co-efficient or Dielectric constant

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

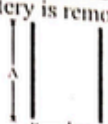

them. $\epsilon_r = \frac{C_{med}}{C_{vac}}$

CRITICAL THINKING?

- In the presence of dielectric material, the electric field between the plates of the capacitor will be
A. Zero
B. Remain same
C. Decrease
D. Increase
- The graph shows the growth of charge with potential difference between plates. The area under the graph shows



- A. Capacitance
B. Separation of plates
C. Energy stored
D. Electric intensity

SEPARATION IS INCREASING		
Quantity	Battery is removed 	Battery remains 
Capacity	Decreases because $C \propto \frac{1}{d}$ i.e., $C_2 < C_1$	Decreases because $C \propto \frac{1}{d}$ i.e., $C_2 < C_1$
Charge	Remains constant because a battery is not present i.e., $q_1 = q_2$	Decreases because battery is present i.e., $q_2 < q_1$. Remaining charge ($q_1 - q_2$) goes back to the battery.
Potential difference	Increases because $V = \frac{q}{C}$ $\Rightarrow V \propto \frac{1}{C}$ i.e., $V_2 > V_1$	$V_2 = V_1$ (since battery maintains the potential difference)
Electric field	Remains constant because $E = \frac{\sigma}{\epsilon_0} = \frac{q}{A\epsilon_0}$ i.e., $E_2 = E_1$	Decrease because $E = \frac{q}{A\epsilon_0}$ and $q_2 < q_1 \Rightarrow E \propto q$ i.e., $E_2 < E_1$
Energy	Increases because $U = \frac{q^2}{2C}$ Here $C_2 < C_1$ and $q_1 = q_2$ i.e., $U_2 > U_1$	Decreases because $U = \frac{1}{2} CV^2$ Here $C_2 < C_1$ but $V_2 = V_1$ i.e., $U_2 < U_1$

SEPARATION IS DECREASING		
Quantity	Battery is removed	Battery remains connected
Capacity	Increases because $C \propto \frac{1}{d}$ i.e., $C_2 > C_1$	Increases i.e., $C_2 > C_1$
Charge	Remains constant because battery is not present i.e., $q_2 = q_1$	Increase because battery is present i.e., $q_2 > q_1$. Remaining charge ($q_2 - q_1$) supplied from the battery.
Potential difference	Decreases because $V = q/C$ $\Rightarrow V \propto \frac{1}{C}$ and $C_2 > C_1$ i.e., $V_2 < V_1$	$V_2 = V_1$ (since battery maintains the potential difference)
Electric field	Remains constant because $E = \frac{\sigma}{\epsilon_0} = \frac{q}{A\epsilon_0}$ and $V_2 = V_1$ i.e., $E_2 = E_1$	Increases because $E = \frac{q}{A\epsilon_0}$ And $q_2 > q_1$ i.e., $E_2 > E_1$
Energy	Decreases because $U = \frac{q^2}{2C}$ And in this case $q_2 = q_1$ and $C_2 > C_1$ i.e., $U_2 < U_1$	Increases because $U = \frac{1}{2} CV^2$ Here $C_2 > C_1$ but $V_2 = V_1$ i.e., $U_2 > U_1$

ENERGY STORED IN A CAPACITOR

- Charge on the plate of capacitor possesses electrical potential energy because of work done to deposit the charge on the plates.

$$P.E = \frac{1}{2}qV$$

$$\text{Energy in capacitor} = \frac{1}{2}CV^2 = \frac{1}{2} \frac{q^2}{C}$$

- Energy is stored in electric field between the plates.

$$\text{Energy} = \frac{1}{2} \left[\frac{\Lambda \epsilon_r \epsilon_0}{d} \right] [Ed]^2$$

$$\text{Energy Density} = \text{Energy/volume} = \frac{1}{2} C_r C_0 E^2$$

Example: A capacitor of capacitance $4 \mu\text{F}$ is charged to 80 V and another capacitor of capacitance $6 \mu\text{F}$ is charged to 30 V . when they are connected together, the energy lost by the $4 \mu\text{F}$ capacitor is

A) 7.8 mJ B) 4.6 mJ C) 3.2 mJ D) 2.5 mJ

Solution: A)

$$V_{\text{common}} = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2} = 50 \text{ V}$$

$$\text{For } 4 \mu\text{F capacitor } E_i = \frac{1}{2} C_1 V_1^2, E_f = \frac{1}{2} C_1 v_c^2$$

$$E_i - E_f = \frac{1}{2} C (v^2 - v_c^2) = 7.8 \times 10^{-3} \text{ J}$$

Grouping of Capacitors:

SERIES 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.
- Charge on each capacitor remains same and equals to the main charge supplied by the battery. $V = V_1 + V_2 + V_3$

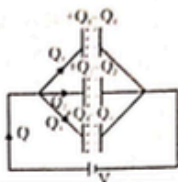
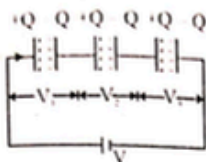
PARALLEL GROUPING

- 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.

- Potential difference across each capacitor remains same and equal to the applied potential difference
 $Q = Q_1 + Q_2 + Q_3$



Equivalent capacitance

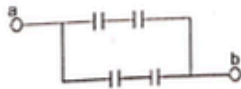
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \text{ or } C_{eq} = (C_1^{-1} + C_2^{-1} + C_3^{-1})$$

$$C_{eq} = C_1 + C_2 + C_3$$

- | | |
|---|---|
| <ul style="list-style-type: none"> In series combination potential difference and energy distribution is in the reverse ratio of capacitance, i.e., $V \propto \frac{1}{C}$ and $P.E \propto \frac{1}{C}$ | <ul style="list-style-type: none"> In parallel combination charge and energy distributes in the ratio of capacitance i.e. $Q \propto C$ and $P.E \propto C$ |
| <ul style="list-style-type: none"> If two capacitors having capacitance C_1 and C_2 are connected in series then $C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$ | <ul style="list-style-type: none"> If two capacitors having capacitance C_1 and C_2 are connected in parallel then $C_{eq} = C_1 + C_2$ |
| <ul style="list-style-type: none"> If n identical capacitors each having capacitance C are connected in series with supplied voltage V then equivalent capacitance $C_{eq} = \frac{C}{n}$ and Potential difference across each capacitor $V' = \frac{V}{n}$ | <ul style="list-style-type: none"> If n identical capacitors are connected in parallel Equivalent capacitance $C_{eq} = nC$ and Charge on each capacitor $Q' = \frac{Q}{n}$ |

CRITICAL THINKING

9. The diagram shows four $6\text{-}\mu\text{F}$ capacitors. The capacitance between points a and b is:



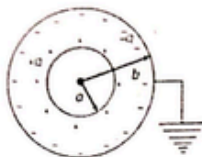
- A. $6\mu\text{F}$
C. $4\mu\text{F}$

- B. $3\mu\text{F}$
D. $9\mu\text{F}$

For Your information:

Spherical Capacitor

It consists of two concentric conducting spheres of radii a and b ($a < b$). Inner sphere is given charge $+Q$, while outer sphere is earthed.



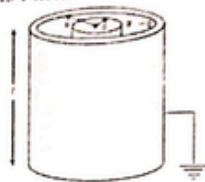
$$\text{Capacitance} = C = 4\pi\epsilon_0 \frac{ab}{a-b}$$

In the presence of dielectric medium (dielectric constant K) between the spheres

$$\text{the } C = 4\pi\epsilon_0 k \frac{ab}{a-b}$$

Cylindrical Capacitor

It consists of two concentric cylinders of radii a and b ($a < b$), inner cylinder is given charge $+Q$ while outer cylinder is earthed. Common length of the cylinders is l then



$$\text{Capacitance} = C = \frac{2\pi\epsilon_0 l}{\log_e \left(\frac{a}{b} \right)}$$

In the presence of dielectric medium (dielectric constant K) capacitance increases by K times and

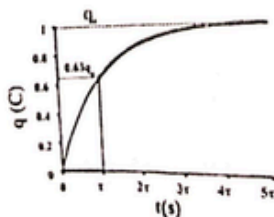
$$C = \frac{2\pi\epsilon_0 k l}{\log_e \left(\frac{a}{b} \right)}$$

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 & C
- **The relation for charging of a capacitor**

$$q = q_0 \left(1 - e^{-\frac{t}{RC}} \right)$$

This relation shows the nature of charging of a capacitor is exponentially, where q_0 represents the maximum charge on the capacitor that stores after an infinite length of time. It means, the rate of charging of a capacitor is different at its different stages, graphically it is represented by



If time $t = 1\tau$ ($1RC$)

$$q = q_0(1 - e^{-\frac{t}{\tau}})$$

$$q = q_0(1 - e^{-1}) \Rightarrow q = q_0(1 - \frac{1}{e})$$

$$q = q_0 \left(1 - \frac{1}{2.718}\right) \Rightarrow q = 0.63q_0$$

This gives that after one time constant, the capacitor will be charged 63%.

For your Information:

If time $t = 2\tau$ ($2RC$)

$$q = q_0(1 - e^{-\frac{2t}{\tau}})$$

Then $q = q_0(1 - e^{-2})$

$$q = 0.86q_0$$

This shows that the capacitor is charged about 86% after 2 time constant.

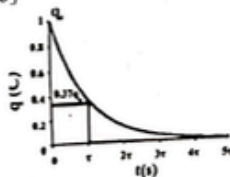
- The relation for discharging is given by

$$q = q_0 e^{-\frac{t}{RC}}$$

If $t = 1\tau(1RC)$

$$q = q_0 e^{-1} = 0.37q_0$$

This shows that discharging of capacitor also decreases exponentially and graphically represented by



It means a capacitor is discharged about 63% or there are 37% charges left on the capacitor

For your Information:

If time $t = 2\tau$ ($2RC$)

$$q = q_0 e^{-2} = 0.14q_0$$

This shows that a capacitor is discharged about 86% or there are 14% charges left on the capacitor after two-time constants.

CRITICAL CONCEPT!

After how many time constants the capacitor will almost discharged?

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.

TOPIC-7 **CURRENT ELECTRICITY**

COURSE CONTENT

- Ohm's Law
- Electrical resistance
- Specific resistance or resistivity
- Effect of temperature on resistance (Temperature coefficient of resistance or resistivity)
- Internal resistance of a supply
- Electric power (unit of electric power)
- Kilowatt-hours

Types of current:

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 $Q = It$

Alternating current (ac)		Direct current (dc)	
(i)		(i) (Pulsating dc)	(Constant dc)
(ii) It's symbol is		(ii) It's symbol is	

Example: The current in a resistor is 8.0 mA. What charge flows through the resistor in 0.020 s?

- A. 0.16 mC B. 1.6 mC C. 4.0 mC D. 0.40 mC

Solution: B. $Q = It$

$$= (8.0 \text{ mA})(0.020 \text{ s})$$

$$= 0.16 \text{ mC}$$

- 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 = 3×10^9 stat ampere
- 1 ampere = 6.25×10^{18} electrons / second.
- 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.

Conventional & Electronic Current

CONVENTIONAL CURRENT	ELECTRONIC CURRENT
Current due to positive charge 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 opposite to direction along the direction of field.

Both conventional and electronic currents are flowing in a circuit, then total current will be given as; $I_{\text{total}} = I_{+ve} + I_{-ve}$

Drift velocity (V_d) It is the average velocity attained by free electrons on applying external electric field. In conductors, $v_d = 10^{-3} \text{ ms}^{-1}$

Current density (J) The current flowing per unit normal area of cross section is defined as current density. i.e. $J = \frac{I}{A} (\text{amp m}^{-2})$. 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.

Due to rotatory motion of charge:

If a point charge q is moving in a circle of radius r with speed v (frequency ν , angular speed ω and time period T) then corresponding currents

$$I = qf = q / T = qf / 2\pi r = q\omega / 2\pi$$

For Your Information:

- An electric shock is a violent disturbance of the nervous system caused by an electrical discharge or current through the body.

CRITICAL THINKING?

1. The diagram shows a model of an atom in which two electrons move round a nucleus in a circular orbit. The electrons complete one full orbit in $1.0 \times 10^{-15} \text{ s}$.



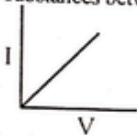
What is the current caused by the motion of the electrons in orbit?

- A. $1.6 \times 10^{-34} \text{ A}$ B. $3.2 \times 10^{-34} \text{ A}$
 C. $1.6 \times 10^{-4} \text{ A}$ D. $3.2 \times 10^{-4} \text{ A}$

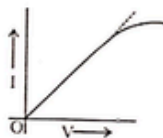
OHM'S LAW

- If the physical conditions of the conductor (temperature etc.) remain constant, then the applied potential difference is directly proportional to the current flowing in it i.e.,
 $I \propto V$ or $V=IR$

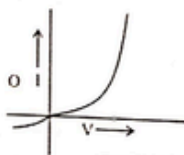
- R is constant called the resistance of the conductor.
- Ohmic substances** The substances which obeys Ohm's law is called ohmic substances. Metals are ohmic substances. Graph for ohmic substances between V and I is a straight line.



- Ohm's law is only applicable in metallic conductors. So it won't work in the case of non-metallic conductors.
- Non-ohmic substances** Those substances which do not obey Ohm's law are called non-ohmic substances. Semiconductor diodes and filament bulbs are non-ohmic substances. Graph between V and I for non-ohmic substances is not a straight line but a curve. It is shown in figure.



For Filament



For Diode

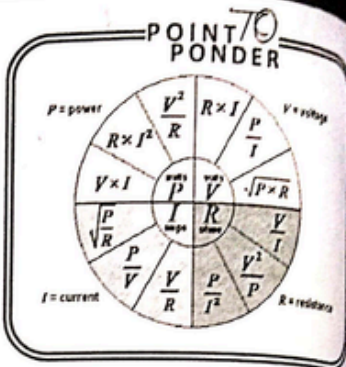
- Slope of I-V graph is equal to conductance.
(If V along x-axis and I along y-axis)
- Slope of I-V graph is equal to resistance.
(If I along x-axis and V along y-axis)

For Your Information:

- Flow of current is directly proportional to the potential difference.
- Flow of heat is directly proportional to the temperature difference.

CRITICAL THINKING?

2. Which one of the following material is non-ohmic:
- A. Gold
 B. Germanium
 C. Copper
 D. Silver



ELECTRICAL RESISTANCE

It is the property of a conductor, by virtue of which it opposes the flow of current in it.

$$R = \frac{V}{I} = \frac{\text{Potential difference between the end of conductor}}{\text{Current flowing in the conductor}}$$

Unit of R is ohm in M.K.S. system and stat-ohm in C.G.S. system and

$$1 \text{ ohm} = \frac{1}{9 \times 10^{11}} \text{ stat ohm}$$

Unit ohm The resistance of a wire, through which a current of 1 ampere flows on applying a potential difference of 1 volt across its ends, is defined as one ohm.

Resistance depends upon

The area of cross-section of the conductor $(R \propto \frac{1}{A})$

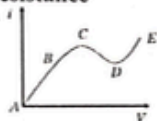
The length of the conductor $(R \propto L)$

The nature of material of the conductor $\therefore R = \rho \frac{L}{A}$

Where ρ is known as the specific resistance or resistivity.

The temperature of the conductors.

Example: From the graph between current i & voltage V shown, identify the portion corresponding to negative resistance



A. DE

B. CD

C. BC

D. AB

Solution: $R = V/i$ in the graph CD has only negative slope. So in this portion R is negative

SPECIFIC RESISTANCE OR RESISTIVITY

The specific resistance of a material is equal to the resistance of the wire of that material with unit cross-sectional area and unit length.

$$\rho = \frac{RA}{L}$$

so, if $L=1\text{m}$ and $A = 1\text{m}^2$ then $\rho = R$

Unit of ρ is ohm meter

Resistivity depends on

(a) nature of material (b) temperature.

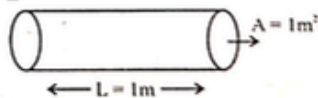
ρ does not depend on the size and shape of the material because it is the characteristic property of the conductor material.

Order of specific resistance $\rho_{\text{alloy}} > \rho_{\text{semiconductor}} > \rho_{\text{conductor}}$

The value of specific resistance (ρ) is minimum for Ag and maximum for tungsten, so

$\rho_{\text{Al}} > \rho_{\text{Cu}} > \rho_{\text{Ag}}$ Hence Ag is best conductor and Cu is second best conductor of electricity.

Constantan, Nichrome, Manganin, Ureka (alloys) and tungsten have high value of ρ , hence resistance of wires of this material is also high.



Example: A wire $l = 8\text{m}$ long of uniform cross-sectional area $A = 8\text{mm}^2$ has a conductance of $G = 2.45\ \Omega^{-1}$. The resistivity of material of the wire will be

A. $2.1 \times 10^{-7}\ \Omega\text{m}$ B. $3.1 \times 10^{-7}\ \Omega\text{m}$ C. $4.1 \times 10^{-7}\ \Omega\text{m}$ D. $5.1 \times 10^{-7}\ \Omega\text{m}$

Solution: C. $\rho = \frac{RA}{l} = \frac{A}{Gl} = \frac{8 \times 10^{-6}}{2.45 \times 8} = 4.1 \times 10^{-7}\ \Omega\text{m}$

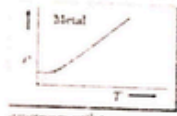
EFFECT OF TEMPERATURE ON RESISTANCE (TEMPERATURE CO-EFFICIENT OF RESISTANCE OR RESISTIVITY)

- Resistance of pure metal (e.g. copper, aluminum) increases with the increase of temperature. The change in resistance is fairly regular for normal range of temperatures.
- The resistance of electrolytes, insulators (e.g. glass, mica, rubber etc.) and semiconductors (e.g. germanium, silicon etc.) decreases with the increase in temperature.
- Resistance of constantan wire does not change with small change of temperature. (Since temperature coefficient of resistance of constantan is very small). Hence standard resistance used in resistance boxes and post office box is made of constantan.
- The reciprocal of resistivity is called conductivity.

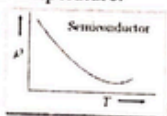
$$\sigma = \frac{1}{\rho} \quad \text{and Unit of } \sigma \text{ is } \frac{1}{\text{ohm metre}} \text{ or } \frac{\text{mho}}{\text{metre}}$$

- Temperature coefficient of resistance (α)** It is the increase in resistance per unit original resistance at 0°C per unit rise (1°C) in temperature. $\alpha = \frac{R_1 - R_0}{R_0 t}$. Its unit is per $^\circ\text{C}$.
- For conductors α is positive i.e., on increasing temperature, resistance increase. For semiconductors (Si, Ge) and insulators (diamond quartz) α is negative, i.e., on increasing temperature resistance decreases.

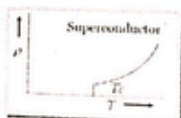
Variation of resistivity with temperature:



ρ increases with temperature



ρ decreases with temperature



ρ decreases with temperature and becomes zero at a certain temperature

CRITICAL THINKING

3. If the resistivity of the conductor is $2 \times 10^{-6} \Omega\text{m}$ then its conductivity is
- A. $2 \times 10^6 \Omega^{-1}\text{m}^{-1}$ B. $5 \times 10^6 \Omega^{-1}\text{m}^{-1}$
 C. $5 \times 10^5 \Omega^{-1}\text{m}^{-1}$ D. $5 \times 10^5 \Omega^{-1}\text{m}^{-1}$

INTERNAL RESISTANCE OF SUPPLY

- emf of a source is defined as potential difference between its output terminals when either its internal resistance is zero or no current is being drawn from it.
- When charge carriers flow through a conductor, they lose 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 output 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

$$V_t = \epsilon - Ir \quad \text{OR} \quad \epsilon = V_t + Ir$$

Example: A new flashlight cell of emf 1.5 volts gives a current of 15 amps, when connected directly to an ammeter of resistance 0.04 ohm. The internal resistance of cell is

- A. 0.04 ohm
 B. 10 ohm
 C. 0.06 ohm
 D. 0.10 ohm

Solution: C. $i = \frac{E}{R+r} \Rightarrow 15 = \frac{1.5}{0.04+r} \Rightarrow r = 0.06\Omega$

CRITICAL THINKING?

4. In the presence of internal resistance of the source, which one of the following relations between potential difference (V) and e.m.f (E) is correct
- A. $E = 0$
 B. $E = V$
 C. $E > V$
 D. $E < V$
5. A battery whose emf is 40 V has an internal resistance of 5 Ω . If this battery is connected to a 15 Ω resistor R, what will be the voltage drop across R?
- A. 10V
 B. 30V
 C. 15V
 D. 40V

ELECTRICAL POWER

The electrical energy per second is defined as electrical power.

$$\text{Electrical power} = \frac{\text{energy supplied}}{\text{time taken}}$$

$$P = \frac{W}{t} = \frac{QV}{t}$$

$$P = IV$$

$$P = I^2 R \Rightarrow P = \frac{V^2}{R}$$

Where P represents the power dissipation.

Heat produced due to power dissipation is given as;

$$H = P \times t$$

$$= I^2 R t = V I t = \frac{V^2 t}{R}$$

If 1J electrical energy is dissipated per second, then power dissipated will be 1 watt.

$$1 \text{ watt} = 1 \text{ J/s}$$

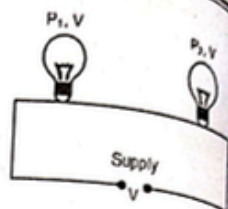
Joule's law:

The amount of heat generated in a resistance due to flow of charges is equal to product of square of current I, resistance R and the time duration t.

$$W = I^2 R t$$

Combination of Bulbs:**Bulbs in Series:**

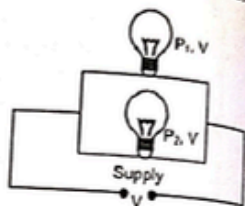
- Total power consumed $\frac{1}{P_{\text{total}}} = \frac{1}{P_1} + \frac{1}{P_2} + \dots$
- If 'n' bulbs are identical, $P_{\text{total}} = \frac{P}{n}$
- P_{consumed} (Brightness) $\propto V \propto R \propto \frac{1}{P_{\text{total}}}$ i.e. in series



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
- $P_{\text{total}} = P_1 + P_2 + P_3 + \dots + P_n$
- If 'n' identical bulbs are in parallel $P_{\text{total}} = nP$
- 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. $R_A = R_B$

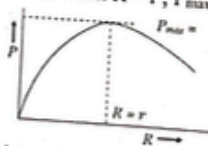
D. None of these

Solution: B. In parallel $P_{\text{consumed}} \propto \text{Brightness} \propto 1/R$

$P_A > P_B$ (given) $R_A < R_B$

Maximum power output:

- Power delivered will be maximum when $R = r$, $P_{\text{max}} = E^2/4r$



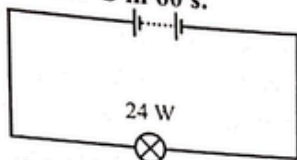
- Maximum power is delivered to a load R when the internal resistance of the source of emf is equal to the load resistance, also called maximum power transfer theorem. The value of the maximum output power is

$$(P_{\text{out}})_{\text{max}} = \frac{E^2}{4r} = \frac{E^2}{4R}$$

- 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 1kWh."
 $1 \text{ kWh} = 1000 \text{ W} \times 3600 \text{ sec}$
 $= 3.6 \times 10^6 \text{ J}$
- $J = 2.77 \times 10^{-7} \text{ kWh}$
- $E (\text{kWh}) = P (\text{W}) \times t (\text{h}) / 1000$
- Cost of electricity = kWh x Unit Price

CRITICAL THINKING ?

6. A battery is used to light a 24 W electric lamp. The battery provides a charge of 120 C in 60 s.



- What is the potential difference across the bulb?
- A. 5 V
B. 12 V
C. 24 V
D. 120 V
7. An electric iron is marked 20 volts 500W. The units consumed by it in using it for 24 hours will be _____
- A. 12
B. 24
C. 5
D. 1100

TOPIC-8 >> ELECTROMAGNETISM

COURSE CONTENT

- Magnetic field
- Magnetic Flux and Magnetic Flux Density
- Force acting on a charged particle in a uniform magnetic field.
- Path followed by charge particle shot in the magnetic field in the direction perpendicular to the field.

MAGNETIC FIELD

- Study of magnetic properties is called magnetism.
- Study of magnetic properties associated with electricity and 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.
- Magnetic field arises due to moving charges.

Characteristics of a Magnet

- It has two poles.
- North Pole of magnet coincides with the South Pole of earth's magnet & vice versa.
- Freely suspended magnet sets itself along N-S direction.
- **An un-magnetized magnetic material can be magnetized as follows;**
 - + By electric method (passing strong D.C)
 - + By single touch or double touch methods.
- **Magnet can be demagnetized as follows;**
 - + By passing A.C
 - + By heating strongly
 - + By striking a magnet again and again with a surface like that of earth. e.g by hammering.

Magnetic Effect of Current

When an electric current is passed through a conductor then a magnetic field is produced around the conductor. It is called the magnetic effect of current.

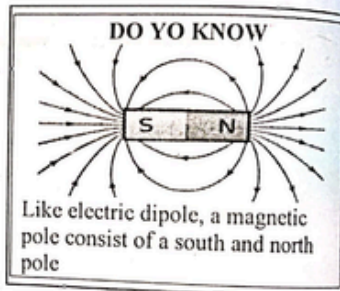
Magnetic field (B): The region of space around a magnet in which its magnetic effects are experienced, is defined as magnetic field.

- It is a vector quantity.
- Unit intensity of magnetic field (B) is weber m^{-2} or Newton/ampere meter or tesla in M.K.S. system and Maxwell/cm² or Gauss or Oersted in C.G.S. system.

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.

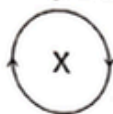
- The lines of force are circular and their direction depends upon the direction of current.
- The magnetic field lasts only as long as the current is flowing through the wire.



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

CRITICAL THINKING?

1. Magnetic field lines form ___ loops from pole to pole.
- A. Open
B. Closed
C. Branched
D. Either closed or branched

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; $\vec{F}_m = I(\vec{L} \times \vec{B})$

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.

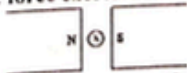
- If $F_m = 1\text{N}$, $I = 1\text{A}$, $L = 1\text{m}$ & $\theta = 90^\circ$, then $B = 1$ tesla

$$1\text{T} = \frac{\text{N}}{\text{A.m}}$$

Gauss is a small unit of B. $1\text{T} = 10^4 \text{G}$

CRITICAL THINKING?

2. The diagram shows a straight wire carrying a flow of electrons into the page. The wire is between the poles of a permanent magnet. The direction of the magnetic force exerted on the wire is



A. ↓

B. →

C. ←

D. ↑

MAGNETIC FLUX AND MAGNETIC FLUX DENSITY

MAGNETIC FLUX:

Magnetic flux is a measurement of the total magnetic field lines which passes through a given area.

The scalar product of magnetic field strength (B) and the vector area (A) is

$$\phi = \vec{B} \cdot \vec{A}$$

If the magnetic field is not perpendicular to the plane, but makes an angle θ with the normal to the plane the flux linked with the plane will be

$$\phi = (B \cos\theta) A = BA \cos\theta$$

Maximum Flux:

If the angle between B and A is 0° the flux will be maximum.

$$\phi_{\max} = BA$$

Minimum Flux:

If the angle between B and A is 90° then magnetic flux will be zero

$$\phi_{\min} = 0$$

Unit of Magnetic Flux:

The unit of magnetic flux ϕ is weber.

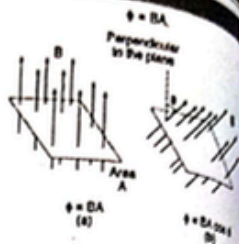
Magnetic flux density:

The magnetic induction B is the flux per unit area of a surface perpendicular to B is also called as flux density.

- Formula: $B = \frac{\phi}{A}$

Unit:

- weber metre⁻²
- Newton/amp-meter.
- Unit of B is also called tesla. In C.G.S. system unit of magnetic flux density is gauss.
1 tesla = 10^4 gauss



CRITICAL THINKING

3. The magnetic field in a certain region is given by $40\hat{i} - 18\hat{k}$. How much flux passes through a 5.0 cm^2 area loop in this region if loop lies flat in YZ plane?
- A. $90 \times 10^{-4} \text{ Wb}$ B. $2 \times 10^{-2} \text{ Wb}$
C. $2 \times 10^2 \text{ Wb}$ D. $9 \times 10^{-4} \text{ Wb}$

FORCE ACTING ON A CHARGED PARTICLE IN A UNIFORM MAGNETIC FIELD

Magnetic Force on a Moving Charge

When a charged particle of charge q is moving with velocity v in a magnetic field B at an angle θ , then force acting on the particle:

$$\vec{F}_m = q(\vec{v} \times \vec{B}) \quad \text{or} \quad F = qvB \sin\theta$$

Where θ is angle between \vec{v} and \vec{B} .

- Direction of force F is perpendicular to both v and B , this direction can be find out by "Fleming's left hand rule".

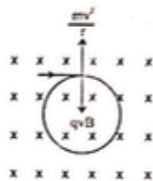
For electron $F = -e(\vec{v} \times \vec{B})$ and for proton $F = +e(\vec{v} \times \vec{B})$

CRITICAL THINKING ?

4. A 2MeV proton is moving perpendicular to a uniform magnetic field of 2.5T. The force on the proton is:
 A. $2.5 \times 10^{10}\text{N}$
 B. $7.6 \times 10^{11}\text{N}$
 C. $2.5 \times 10^{11}\text{N}$
 D. $7.6 \times 10^{12}\text{N}$
5. A proton is moving along z-axis in a magnetic field. The magnetic field is along x-axis. The proton will experience a force along
 A. x-axis
 B. y-axis
 C. z-axis
 D. -ve z-axis

PATH FOLLOWED BY CHARGE PARTICLE IN MAGNETIC FIELD

- If $v = 0$, then $F = 0$
- If $\theta = 0^\circ$, then $F = qvB \sin \theta = 0$
 So the particle will continue to move in straight line with the same speed.
- If $\theta = 180^\circ$, then $F = qvB \sin 180$ or $F = 0$
 Here also the particle will move in same direction in straight line with same speed.
- If $\theta = 90^\circ$, then $F = qvB \sin 90$ or $F_{\max} = qvB$
 In this case the charged particle will move in circular path and the plane of the circle is perpendicular to B.



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

$$\text{or } r = \frac{mv}{qB}$$

CRITICAL CONCEPT!

A force exerts on a moving charged particle in a magnetic field, but in what direction it moves that the force does not exert on it?

r is called radius of circular path or cyclotron radius.

$$\therefore \text{Angular velocity or angular frequency of the particle: } \omega = \frac{v}{r} = \frac{qB}{m}$$

$$\text{So, } \omega = \frac{qB}{m} \quad \text{But } \omega = 2\pi f$$

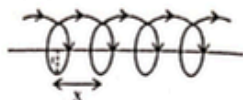
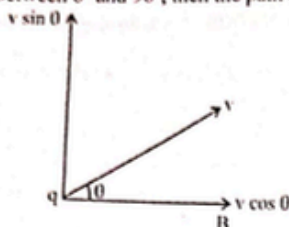
$$\text{or } f = \frac{\omega}{2\pi} = \frac{qB}{2\pi m}$$

Also time period of particle $T = \frac{1}{f} = \frac{2\pi m}{qB}$ and kinetic energy of particle

$$\text{K.E} = \frac{1}{2}mv^2 = \frac{1}{2}m \left(\frac{rqB}{m} \right)^2$$

$$\text{so } \text{K.E} = \frac{r^2 q^2 B^2}{2m}$$

- If θ lies between 0° and 90° , then the path of the particle is helical or helix



Here radius of helix $r = \frac{mv \sin \theta}{qB}$ and pitch of helix

$$x = v \cos \theta \times T = v \cos \theta \times \frac{2\pi m}{qB} \quad \therefore T = \frac{2\pi m}{qB}$$

Force on Charge Particle in An Electric and Magnetic Field:

$$\text{As, } \vec{F}_e = q\vec{E}, \text{ and } \vec{F}_m = q(\vec{v} \times \vec{B})$$

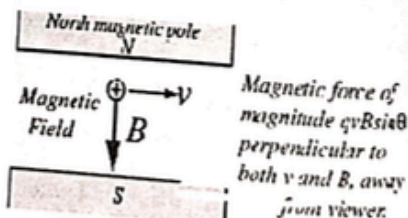
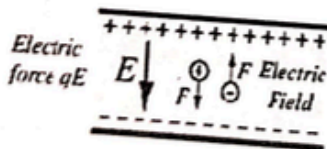
$$\text{or } \vec{F} = \vec{F}_e + \vec{F}_m$$

$$\text{or } \vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$$

Where \vec{F} is called Lorentz force. If charge is of mass 'm' in uniform electric field, then

$$\vec{a} = \frac{\vec{F}}{m}$$

- Electric force does work
- Magnetic force does no work



Example: A particle of charge -16×10^{-18} C moving with velocity 10 m/s along the x-axis enters a region where a magnetic field of induction B is along the y-axis and an electric field of magnitude 10^4 V/m is along the negative z-axis. If the charged particle continues moving along the x-axis, the magnitude of B is

- A. 10^3 Wb m^{-2}
C. $10^{16} \text{ Wb m}^{-2}$

- B. 10^5 Wb m^{-2}
D. $10^{-3} \text{ Wb m}^{-2}$

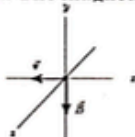
Solution: A. $\vec{F} = \vec{F}_e + \vec{F}_m, \vec{F} = q\vec{E} + q(\vec{v} \times \vec{B}) = 0 \Rightarrow B = \frac{E}{v} = 10^3 \text{ Wb m}^{-2}$

Difference between Electric and Magnetic Forces

Sr.No.	Electric Force	Magnetic Force
1	Electric force on a charged particle is always collinear with the field.	Magnetic force on a charge particle is always perpendicular to the field.
2	Electric force ($q\vec{E}$) is independent of the state of rest of the motion of the charged particle.	Magnetic force is velocity dependent i.e. acts only when the charged particle is in motion.
3	Electric force does work in displacing the charged particle.	Magnetic force does no work when the charged particle is displaced.
4	Electric force, $\vec{F} = q\vec{E}$	Magnetic force, $\vec{F} = q(\vec{v} \times \vec{B})$ $= qvB\sin\theta$ When $\theta = 0$ Force = 0 When $\theta = 90^\circ$ $F = qvB(\text{max})$
5	Electric force may or may not be non-central.	Magnetic force is always non-central.

CRITICAL THINKING ?

6. An electron moves in the negative x direction, through a uniform magnetic field in the negative y direction. The magnetic force on the electron is



- A. In the negative z direction
B. In the positive z direction
C. In the negative y direction
D. In the positive y direction
7. Two charged particles M and N are projected with same velocity in a uniform magnetic field. Then M and N are:



- A. A proton and α -particle respectively
B. A deuteron and an electron respectively
C. An electron and a proton respectively
D. A protium and a proton respectively

e/m FOR AN ELECTRON

- 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:

Potential difference method: $v = \sqrt{2V_e} \frac{e}{m}$

so that $\frac{e}{m} = \frac{2V_e}{B^2 r^2}$

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

- Among charge particles alpha, proton and electron, the maximum e/m is for electron.
- e/m of neutron is zero, as neutron has no charge.

Conditions for e/m in uniform Magnetic field

If speed v is constant	If Momentum is constant	If K.E is constant
$\frac{e}{m} = \frac{v}{Br}$	$\frac{e}{m} = \frac{v}{Br}$	$\frac{e}{m} = \frac{v}{Br}$
$r = \frac{mv}{Be}$	$r = \frac{mv}{Be} = \frac{p}{Be}$	$r = \frac{mv}{Be} = \frac{p}{Be} = \frac{\sqrt{2mK.E}}{Be}$
$r \propto \frac{m}{e}$	$r \propto \frac{1}{e}$	$r \propto \frac{\sqrt{m}}{e}$

Example: Four particles independently move at the same speed in a direction perpendicular to the same magnetic field. Which particle is deflected the most?

- A. A copper ion B. A helium nucleus
C. An electron D. A proton

Solution: The force exerted on a particle by the magnetic field is given by Bqv . As this force provides the necessary centripetal force to deflect the particle.

$$Bqv = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{Bq}$$

For a large deflection, r is small. Among the four particles, the electron has the lowest $\frac{m}{q}$ ratio.

CRITICAL THINKING

8. An electron enters a region where the electric field E is perpendicular to the magnetic field B. It will suffer no deflection if

- A. $E = Bev$ B. $B = cE/v$
C. $E = Bv$ D. $E = Bev/2$

COURSE CONTENT

- Electromagnetic induction
- Faraday's Law
- Lenz's Law and conservation of energy
- Alternating Current Generator
- Transformers

ELECTROMAGNETIC INDUCTION

- "When the magnetic flux linking a conductor changes, an e.m.f is induced in the conductor, this phenomenon is known as electromagnetic induction". Induction is the change in flux linking the conductor (or coil)
- The product of number of turns (N) of the coil and the magnetic flux (Φ) linking the coil is called flux linkages i.e.
Flux linkages = $N\Phi$
- 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

DO YOU KNOW



Electronic card swapping system based on the electromagnetic induction theory

FARADAY'S LAW

Faraday's Laws of Electromagnetic Induction

Faraday has given the following two laws regarding electromagnetic induction.

- Whenever there is a change in the magnetic flux linked with a circuit, an induced emf is produced in the circuit. If the circuit is closed, an induced current flows through it. The current flows only so long as the magnetic flux is changing.
- The induced emf is equal to the negative rate of change of magnetic flux. Thus, if $\Delta\phi$ be the change in flux in time interval Δt , then the induced emf in the circuit is

$$\epsilon = -\frac{\Delta\phi}{\Delta t}, \text{ N number of turns, } \epsilon = -N\frac{\Delta\phi}{\Delta t}$$

Topic-9

- The negative sign shows the induced emf opposes the change in magnetic flux.
- If rate of change of magnetic flux be in weber/sec, the induced emf will be in volt.
- If the coil contains N turns $\epsilon = -N \frac{\Delta\phi}{\Delta t} = \frac{\Delta(N\phi)}{\Delta t}$

Example: A flat circuit coil of 120 turns, each of area 0.070 m^2 , is placed with its axis parallel to a uniform magnetic field. The flux density of the field is changed steadily from 80 mT to 20 mT over a period of 4.0 s . Induced emf will be

- A. 0 B. 130 mV C. 170 mV D. 500 mV

Solution: B. $\epsilon = NA \frac{\Delta B}{\Delta t}$

$$= 120 \times 0.070 \times \frac{(80 - 20) \times 10^{-3}}{4.0}$$

$$= 0.126 \text{ V}$$

$$= 130 \text{ mV}$$

Induced Current:

Induced emf in a coil is given by $\epsilon = -N \frac{\Delta\phi}{\Delta t}$. If the coil be closed and the total resistance

of its circuit be R , then the induced current in the circuit is $I = \frac{\epsilon}{R} = \frac{N \Delta\phi}{R \Delta t}$.

Induced Charge:

The charge flowing through the circuit in time interval Δt is

$$q = I \times \Delta t = \frac{N \Delta\phi}{R \Delta t} \times \Delta t = \frac{N}{R} \Delta\phi.$$

CRITICAL THINKING

1. Emf (ϵ_1) is induced in circular coil of 100 turns in which magnetic flux changes from 20 Wb to 40 Wb in 1s. While emf (ϵ_2) is induced in another coil of same number of turns in which magnetic flux changes from 30 Wb to 150 Wb in 1minute which of following is correct.
- A. $\epsilon_1 = \epsilon_2$ B. $\epsilon_1 > \epsilon_2$
 C. $\epsilon_1 < \epsilon_2$ D. $\epsilon_1 = \epsilon_2 = 0$

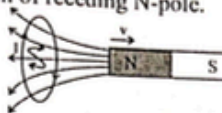
LENZ'S LAW AND CONSERVATION OF ENERGY

According to Lenz's rule the induced current produced in a closed circuit always flows in such a direction that it opposes the cause due to which it has been produced itself.

- In general, the direction of induced emf of current is determined by "Lenz's law", in case of motion of straight conductor in a magnetic field, it can be also be determined by the "Fleming's right hand rule."
- When the north pole of a magnet moves towards a stationary loop, an induced current I flow in the anticlockwise sense as seen from the side on which the magnet is located. The anticlockwise sense corresponds to the generation of north pole (\curvearrowright) which opposes the motion of the approaching N-Pole of the magnet.



When the N-pole of the magnet is moved away from the loop, the current I flows in the clockwise sense which corresponds to the generation of south-pole (\curvearrowright). The induced south pole opposes the motion of receding N-pole.



Because in each case induced current opposes the motion of magnet hence some mechanical work has to be done on the system to move the magnet against this opposing force. According to law of conservation of energy, this work is obtained in the coil in the form of heat energy.

If induced current was not to oppose the motion of magnet, then we could be getting electrical energy continuously without doing any work which is never possible. Hence, Lenz's rule is the necessity of law of conservation of energy.

CRITICAL THINKING?

- If current in conductor increases, then according to Lenz's law self-induced voltage will

 - Aid the increasing current
 - Tend to decrease the amount of current
 - Produce current opposite to increasing current
 - Aid the applied Volta
- In the diagram shown if a bar magnet is moved along the common axis of two single turn coils A and B in the direction of arrow

 - Current is induced only in A & not in B
 - Induced currents in A & B are in the same direction
 - Induced currents in A & B are in opposite directions
 - Current is induced only in B and not in A

ALTERNATING CURRENT 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;

$$\epsilon = N(2vB(\sin\theta)) \text{ also } \epsilon = N \omega AB \sin \omega t$$

$$\text{then } \epsilon_{\max} = N \omega AB \text{ when } \theta = 90^\circ$$

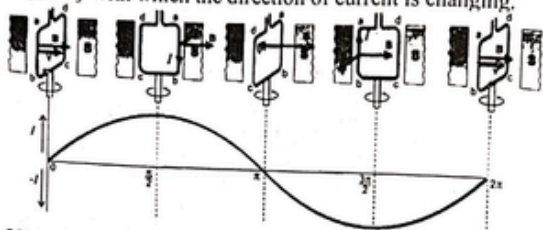
$$\epsilon = \epsilon_{\max} \sin \omega t \text{ If } \omega = 2\pi f, \text{ then}$$

$$\epsilon = \epsilon_{\max} \sin 2\pi ft$$

In terms of potential difference, $V = V_0 \sin 2\pi ft$

In terms of current, $I = I_0 \sin 2\pi ft$.

where f is the frequency with which the direction of current is changing.



- In Pakistan $f = 50\text{Hz}$, it means 50 times in a second direction is changing.

For your Information:

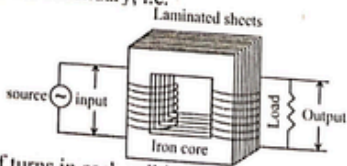
An Electric generator is an electric motor with its input and output reversed.

CRITICAL THINKING

4. In ac generator, ac current reverses its direction
- A. 10 times per second B. 20 times per second
- C. 50 times per second D. 40 times per second

TRANSFORMER

It is a device which rises or lowers the voltage in A.C. circuits through mutual induction and consists of two coils wound on the same core. The coil which is connected to the source (i.e., to which input is applied) is called primary while the other which is connected to the load (i.e., from which output is taken) is called secondary. The alternating current passing through the primary creates a continuously changing flux through the core. This changing flux induces an alternating emf in the secondary. As magnetic lines of force are closed curves, the flux per turn of the primary must be equal to the flux per turn of the secondary, i.e.



And as the number of turns in each coil is constant,

$$\frac{\phi_s}{N_s} = \frac{\phi_p}{N_p} \quad \text{or} \quad \frac{\epsilon_s}{\epsilon_p} = \frac{N_s}{N_p} \quad \left[\text{as } \epsilon = \frac{\Delta\phi}{\Delta t} \right]$$

And as in an ideal transformer there is no loss of power, so $E = V$ and $P = VI = \text{constant}$,

$$\text{So, } \frac{V_s}{V_p} = \frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Now there are two possibilities

- (i) $N_s > N_p$ the transformer is said to be "step up" and it increases voltage and reduces current.
- (ii) $N_s < N_p$ the transformer is said to be "step down" and it reduces voltage and increases current.

Transformer works on A.C. only and never on D.C.

- It can increase or decrease either voltage or current but not both simultaneously (as power = constant).

Example: The secondary coil of an ideal transformer delivers an r.m.s current of 2.5 A to a load resistor of resistance 8.0 Ω . The r.m.s current in the primary is 10 A. What is the r.m.s. potential difference across the primary coil?

- A. 3.5 V B. 5.0 V C. 57 V D. 80 V

Solution: B. r.m.s potential difference across the secondary coil
 $= (2.5)(8)$
 $= 20 \text{ V}$

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} \Rightarrow V_p = \frac{I_s}{I_p} \times V = \frac{2.5}{10} \times 20 = 5.0 \text{ V}$$

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.

- Flux Losses:**

The coupling of the primary and secondary 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 hysteresis 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) **Hysteresis 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 hysteresis. To minimize this loss, we choose material of core of smaller hysteresis loss generally soft iron.

CRITICAL CONCEPT

If a primary coil of transformer is connected to a D.C source, is there an emf induced in the secondary coil?

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%).

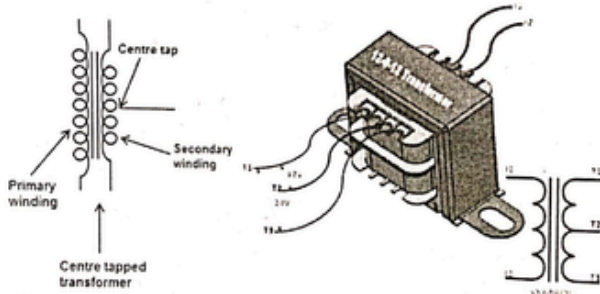
Efficiency is given by $\eta = \frac{\text{Output power}}{\text{Input power}} \times 100$. In terms of secondary and primary

voltages and currents, $\eta = \frac{V_s I_s}{V_p I_p}$. Also since, **Input = Output + Losses**, so

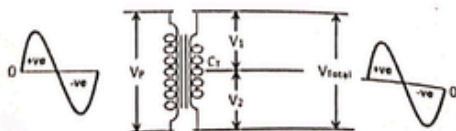
$$\eta = \frac{\text{Output power}}{\text{Input power} + \text{Losses}}$$

Center tapped transformer:

- When an additional wire is connected across the exact middle of the secondary winding of a transformer, it is known as a center tapped transformer.
- A **center-tapped transformer** also known as **two phase three wire transformer** is normally used for rectifier circuits.



- The wire is adjusted in such a way that it falls in the exact middle of the secondary winding. So, the wire is exactly at zero volts of the AC signal at the center tap.
- The center tapped transformer works almost similar to a normal transformer. Like a normal transformer, the center tapped transformer also increases or reduces the AC voltage.
- However, a center tapped transformer has another important feature. That is the secondary winding of the center tapped transformer divides the input AC current or AC signal (V_p) into two parts.



$$V_{\text{total}} = V_1 + V_2$$

$$Cr = \text{Centre tap}$$

- The upper part of the secondary winding produces a positive voltage V_1 and the lower part of the secondary winding produces a negative voltage V_2 . When we combine these two voltages at output load, we get a complete AC signal.

$$\text{i.e. } V_{\text{Total}} = V_1 + V_2$$

$$\text{so } \frac{V_1}{V_p} = \frac{N_1}{N_p}$$

$$\text{and } \frac{V_2}{V_p} = \frac{N_2}{N_p}$$

where

V_1 = Voltage across the first half of Secondary coil

V_2 = Voltage across the second half of Secondary coil

V_p = Voltage across the Primary coil

N_1 = Number of turn in the first half of Secondary coil

N_2 = Number of turn in the second half of Secondary coil

N_p = Number of turn in the Primary coil

CRITICAL THINKING

- The coils of a stepdown transformer have 500 and 5000 turns. In the primary coil an AC of 4 A at 2200 volt is sent. The value of the current and potential difference in the secondary will be.

A. 20 A, 22V	B. 0.4 A, 22000 A
C. 40 A, 220V	D. 40 A, 22000V
- The turns ratio of a transformer is $\frac{1}{2}$. If a dry cell of emf 1.5 volt is connected with primary coil then emf establish in secondary coil is?

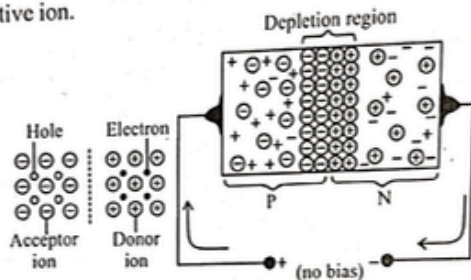
A. 0.75 V	B. 3 V
C. 1.5 V	D. Zero

Rectification

RECTIFICATION

P-N JUNCTION AND ITS CHARACTERISTICS

- P-N junction is developed from a single crystal by introducing donor impurities on one side and acceptor into the other side.
- The donor ion is represented by a plus (+) sign, because this impurity atom donates an electron, hence it becomes a positive ion.
- The acceptor ion is indicated by a minus (-) sign; because it accepts an electron hence it becomes a negative ion.



- Due to density difference across the junction the holes initially diffuse towards N-side, where the number of holes is lesser. Similarly, electron diffuse to P-side of junction.
- Migration of electrons and holes across junction due to concentration difference is termed **diffusion**.
- At the junction on both sides a region is formed which is depleted of charge carriers. This region is called depletion region whose thickness is about 10^{-6} m.
- An electric field is developed across the junction which is in a direction to oppose the further diffusion of electrons from N-side.
- The potential developed across the barrier layer is called **barrier potential**. It is 0.7 volts for silicon diode and 0.3 volts for germanium diode.
- When no external source is connected to diode, it is called unbiased. It has two electrodes hence it is called diode.

FORWARD BIASED P-N JUNCTION

When the voltage is applied to the P-N junction diode in such a way that the positive terminal of the battery is connected to the p-type semiconductor and the negative terminal of the battery is connected to the n-type semiconductor, the diode is said to be forward biased.

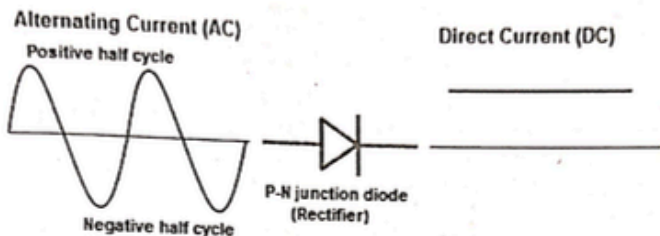
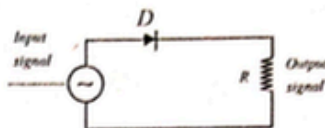
REVERSE BIASED P-N JUNCTION

When the voltage is applied to the P-N junction diode in such a way that the positive terminal of the battery is connected to the n-type semiconductor and the negative terminal of the battery is connected to the p-type semiconductor, the diode is said to be reverse biased.

Rectification:

Conversion of alternating current into direct current is called rectification.

- The P-N junction diode acts like a rectifier by converting the AC current into DC current.



- There are two very common types of rectification.

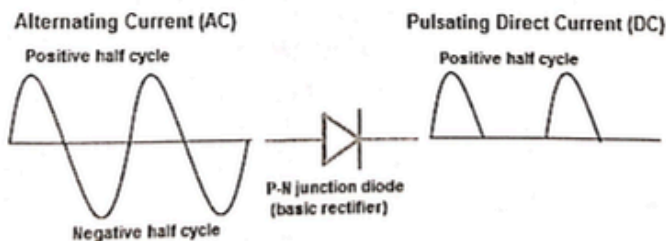
Half-wave rectification (HWR)

- A half wave rectifier is a type of rectifier which converts the positive half cycle (positive current) of the input signal into pulsating DC (Direct Current) output signal.

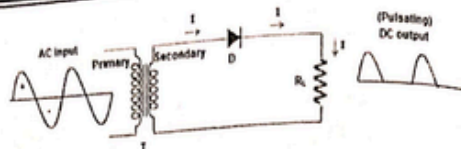
Or

A half wave rectifier is a type of rectifier which allows only half cycle (either positive half cycle or negative half cycle) of the input AC signal while the another half cycle is blocked.

- One diode is used to construct the half wave rectifier.
- The DC current produced by a basic rectifier (half wave rectifier) is not a pure DC current. It is a pulsating DC current.



- The pulsating DC current starts from zero and grows to the maximum forward current (peak level), and decreases to zero. However, the pulsating DC current does not change its direction periodically like AC current.
- The half wave rectifier is made up of an AC source, transformer (step-down), diode, and resistor (load). The diode is placed between the transformer and resistor (load).

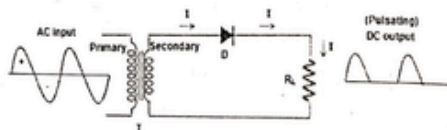


I = Current
 D = Diode
 R_L = Load resistor
 T = Transformer
 \bullet = Positive half cycle
 \cdot = Negative half cycle
 Half wave rectifier

- In half wave rectifier, we generally use a step-down transformer because the voltage needed for the diode is very small.
- Applying a large AC voltage without using transformer will permanently destroy the diode.
- A resistor restricts the current flow to a certain level

Positive half wave rectifier

- The low AC voltage produced by the step-down transformer is directly applied to the diode.

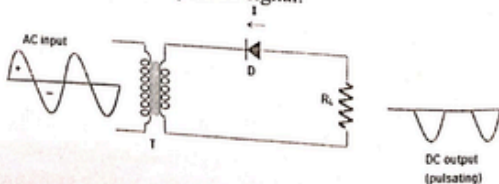


I = Current
 D = Diode
 R_L = Load resistor
 T = Transformer
 \bullet = Positive half cycle
 \cdot = Negative half cycle
 Positive half wave rectifier

- When low AC voltage is applied to the diode (D), during the positive half cycle of the signal, the diode is forward biased and allows electric current whereas, during the negative half cycle, the diode is reverse biased and blocks electric current.

Negative half wave rectifier

- The construction and working of negative half wave rectifier is almost similar to the positive half wave rectifier. The only thing we change here is the direction of a diode.
- Unlike the positive half-cycle of input AC signal, the negative half wave rectifier allows electric current during the negative half-cycle of the input AC signal and blocks electric current during the positive half-cycle of the input AC signal.

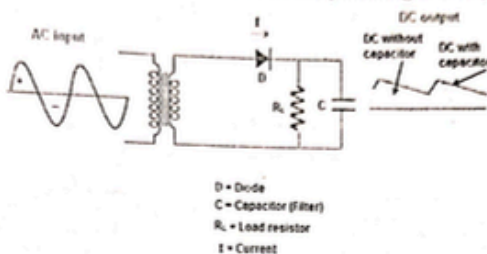


Negative half wave rectifier

- During the negative half cycle, the diode is forward biased and during the positive half cycle the diode is reverse biased, so the negative half wave rectifier allows electric current only during the negative half cycle.

Half wave rectifier with capacitor filter:

- A filter converts the pulsating direct current into pure direct current. In half wave rectifiers, a capacitor is used as a filter to convert the pulsating DC to pure DC.



Half wave rectifier with filter capacitor

Ripple factor:

- In the output pulsating DC signal, we find ripples. These ripples in the output DC signal can be reduced by using filters such as capacitors
- In order to measure how much ripples are there in the output DC signal we use a factor known as ripple factor. The ripple factor is denoted by γ .
- The ripple factor tells us the amount of ripples present in the output DC signal.
- A large ripple factor indicates a high pulsating DC signal while a low ripple factor indicates a low pulsating DC signal.

$$\text{Ripples factor} = \frac{\text{rms value of AC component of the output voltage}}{\text{DC component of the output voltage}}$$

- The ripple factor is given as

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1} = 1.21$$

- The high ripples in the half wave rectifier can be reduced by using filters
- For upper half or lower half is rectified.

$$\% \eta = \frac{\text{output power of DC}}{\text{input power of AC}} \times 100$$

- The rectifier efficiency of a half wave rectifier is 40.6%
- Can be used for charging battery.
- Output frequency is equal to input frequency.

$$V_{av} = V_{DC} = \frac{V_o}{\pi}$$

$$V_{rms} = \frac{V_o}{2}$$

Draw Backs

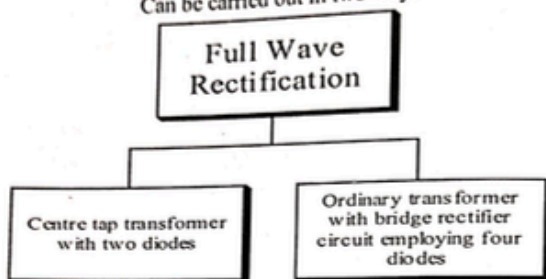
- More ripples in the output wave form.
- Average value of the output DC signal drops.

Topic-10

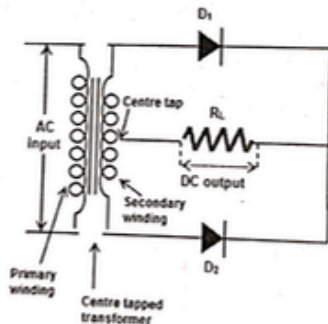
Full wave Rectification (FWR):

- The full wave rectifier is a type of rectifier which converts the full AC input signal (positive half cycle and negative half cycle) to pulsating DC output signal.
- Unlike the half wave rectifier, the input signal is not wasted in full wave rectifier.
- The efficiency of full wave rectifier is high as compared to the half wave rectifier.

Can be carried out in two ways

**Center Tapped Full Wave Rectifier:**

- A center tapped full wave rectifier is a type of rectifier which uses a center tapped transformer and two diodes to convert the complete AC signal into DC signal.
- The center tapped full wave rectifier is made up of an AC source, a center tapped transformer, two diodes, and a load resistor.

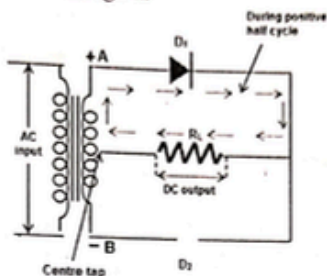


- The AC source is connected to the primary winding of the center tapped transformer. A center tap (additional wire) connected at the exact middle of the secondary winding divides the input voltage into two parts.
- The upper part of the secondary winding is connected to the diode D_1 and the lower part connected to a common load R_L , with the help of a diode D_2 . Both diode D_1 and diode D_2 are
- The center tap is generally considered as the ground point or the zero-voltage reference point.

Working Of Center Tapped Full Wave Rectifier:

- When input AC voltage is applied, the secondary winding of the center tapped transformer divides this input AC voltage into two parts: positive and negative.

During the positive half cycle of the input AC signal, terminal A become positive, terminal B become negative and center tap is grounded (zero volts). The positive terminal A is connected to the p-side of the diode D_1 and the negative terminal B is connected to the n-side of the diode D_1 . So the diode D_1 is forward biased during the positive half cycle and allows electric current through it.



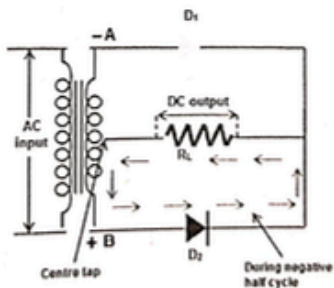
On the other hand, the negative terminal B is connected to the p-side of the diode D_2 and the positive terminal A is connected to the n-side of the diode D_2 . So the diode D_2 is reverse biased during the positive half cycle and does not allow electric current through it.

The diode D_1 supplies DC current to the load R_L . The DC current produced at the load R_L will return to the secondary winding through a center tap.

During the negative half cycle of the input AC signal, terminal A become negative, terminal B become positive and center tap is grounded (zero volts).

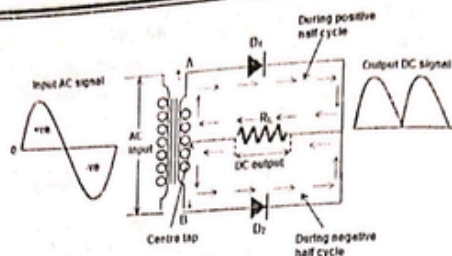
The negative terminal A is connected to the p-side of the diode D_1 and the positive terminal B is connected to the n-side of the diode D_1 .

So, the diode D_1 is reverse biased during the negative half cycle and does not allow electric current through it.

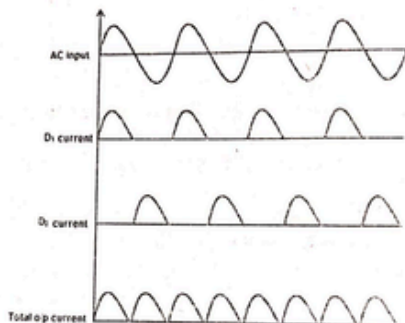


On the other hand, the positive terminal B is connected to the p-side of the diode D_2 and the negative terminal A is connected to the n-side of the diode D_2 . So the diode D_2 is forward biased during the negative half cycle and allows electric current through it.

Thus, the diode D_1 allows electric current during the positive half cycle and diode D_2 allows electric current during the negative half cycle of the input AC signal. As a result, both half cycles (positive and negative) of the input AC signal are allowed. So the output DC voltage is almost equal to the input AC voltage.



The output waveforms of the full wave rectifier is shown in the below figure.



Ripple Factor:

- Ripple factor is defined as the ratio of ripple voltage to the pure DC voltage
- The ripple factor is given by

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2} - 1 = 0.48$$

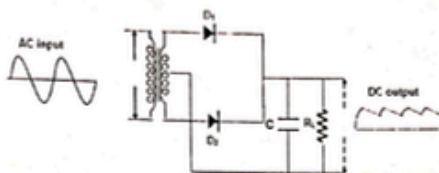
- $\% \eta = \frac{\text{output power of DC}}{\text{input power of AC}} \times 100$
- The rectifier efficiency of a full wave rectifier is 81.2%.
- $V_{av} = \frac{2V_o}{\pi}$
- $V_{rms} = \frac{V_o}{\sqrt{2}}$
- The rectifier efficiency of a full wave rectifier is twice that of the half wave rectifier. So, the full wave rectifier is more efficient than a half wave rectifier.

Advantages of full wave rectifier with center tapped transformer:

- Full wave rectifier has high rectifier efficiency than the half wave rectifier.
- No signal is wasted in a full wave rectifier.
- Low power loss
- The output DC signal in full wave rectifier has fewer ripples than the half wave rectifier.

Disadvantage of full wave rectifier with center tapped transformer:

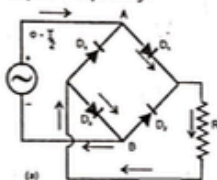
- The center tapped transformers are expensive and occupy a large space
- The full wave rectifier rectifies both positive and negative half cycles, the DC signal obtained at the output still contains some ripples. To reduce these ripples at the output, we use a filter.
- The filter is an electronic device that converts the pulsating Direct Current into pure Direct Current.



Full wave rectifier with capacitor filter

Bridge Rectifier:

- Four diodes are used.
- Two diodes remain ON (FWD Biased) in each half of the input cycle while other two remains off (Reverse Biased) in the same half of the cycle.
- Output frequency is twice of input frequency.

**Summary:**

If input wave has "T" Time period then

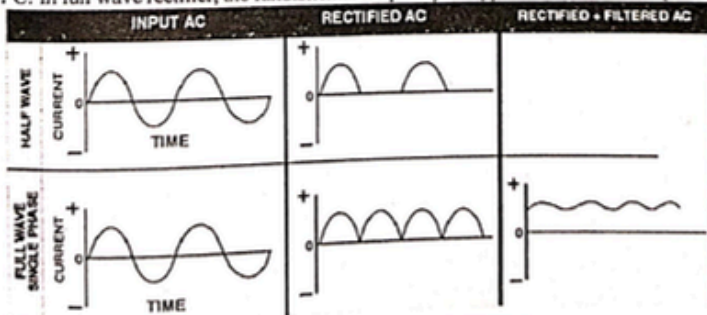
$0 \sim T/2$ D_1 & D_3 - On and D_2 & D_4 - Off

$T/2 \sim T$ D_1 & D_3 - Off D_2 & D_4 - On

Example: If a full wave rectifier circuit is operating from 50 Hz mains, the fundamental frequency in the ripple will be

A. 50 Hz B. 70.7 Hz C. 100 Hz D. 25 Hz

Solution: C. In full wave rectifier, the fundamental frequency in ripple is twice that of input frequency.



Topic-10

Advantages:

- Very inexpensive method of rectification.
- Average values do not drop significantly.
- Lesser ripples are there in the signal compared to Half Wave Rectification.

Example: The electrical circuit used to get smooth DC output from a rectifier circuit is called

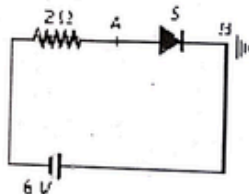
- A. Filter B. Oscillator C. Logic gates D. Amplifier

Solution: A.

'Filter' filters out the fluctuations in the output of the rectifier.

CRITICAL THINKING?

1. The diode shown in the circuit is a silicon diode. The potential difference between the points A and B will be



- A. 0.7V B. 0.6V
C. 0 V D. 6 V
2. In full wave rectification, the output D.C. voltage across the load is obtained for _____
- A. The positive half cycle of input A.C.
B. The negative half cycle of input A.C.
C. The complete cycle of input A.C.
D. All of the above

TOPIC-11 >> DAWN OF MODERN PHYSICS

COURSE CONTENT

- Photon and particle model of light in terms of photons with particular energy

PHOTON

The Photon

- 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 .
- Emission or absorption of energy is applied to any **oscillating system**.
- Einstein defined light in terms of photon which is called photon (particle) theory of light.
- The particle nature of light has been observed in the Compton effect and practically it has been proved in Davission and Germer experiment.

CRITICAL CONCEPT!

The rest mass of photon is zero. Is its momentum also zero?

Salient features of photon:

- A photon behaves as a particle whose rest mass is zero and it travels with speed of light $3 \times 10^8 \text{ms}^{-1}$. In other words, a photon exists as long as it is moving. It ceases to exist when it comes to rest.
- Photons are electrically neutral and are not deflected in the presence of electric and magnetic fields.
- The energy of a photon is given as:

$$E = hf = \frac{hc}{\lambda} \therefore f\lambda = c$$

This shows that the energy of photon depends upon frequency. (or wavelength)

- **Momentum of photon** is given as:

$$\text{As } E = hf = mc^2$$

$$\text{So } mc = \frac{hf}{c}$$

$$p = \frac{hf}{c} = \frac{h}{\lambda}$$

- Rest mass of a photon can be calculated by using Einstein's mass variation equation:

$$m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} \Rightarrow m_0 = m \sqrt{1 - \frac{v^2}{c^2}}$$

Since photon is moving with speed of light 'c' so $v = c$
This shows that rest mass of a photon is zero.

Its effective mass is given as

$$E = mc^2$$

$$m = \frac{E}{c^2} = \frac{h}{c\lambda}$$

This mass is also known as kinetic mass of the photon.

Example: An air station is broadcasting the waves of wavelength 300 m. If the radiating power of the transmitter is 10 kW, then the number of photons radiated per second is

- A. 1.5×10^{29} B. 1.5×10^{31} C. 1.5×10^{33} D. 1.5×10^{35}

Solution: B. If n be the number of photons/s, then $E = \frac{nhc}{\lambda}$

CRITICAL THINKING ?

1. What happens to the energy of a photon when it strikes matter?
- A. It turns into heat B. It turns into electrical energy
C. The matter emits electrons D. All of the above

CRITICAL CONCEPT!

If an electron and a proton having same wavelength. Which particle has higher speed?

Example: A tiny particle of mass 10^{-13} kg moving with a velocity of 10 cm s^{-1} is associated with a wave of wavelength

- A. $6.62 \times 10^{-18} \text{ cm}$ B. $6.62 \times 10^{-2} \text{ cm}$
C. $6.62 \times 10^{-12} \text{ cm}$ D. $6.62 \times 10^{-34} \text{ cm}$

Solution: A. $\lambda = \frac{h}{mv} = \frac{6.62 \times 10^{-34}}{10^{-13} \times 10 \times 10^{-2}} \times 100 \text{ cm} = 6.62 \times 10^{-18} \text{ cm}$

CRITICAL THINKING ?

2. Protons & Alpha particles have same wavelength, what is same for both of them?
- A. energy B. Time period
C. Frequency D. momentum
3. A body of mass 200 g moves at the speed of 5 m/hr. So wavelength related to it is of the order ($h = 6.62 \times 10^{-34} \text{ Js}$)
- A. 10^{-10} m B. 10^{-30} m
C. 10^{-20} m D. 10^{-40} m

PHOTOELECTRIC EFFECT

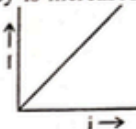
The emission of electrons from metallic surface, when light of specific short wavelength is incident on it is called "Photoelectric effect".

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 increases.

Photoelectric current, $i \propto I$ where $I =$ Intensity of light



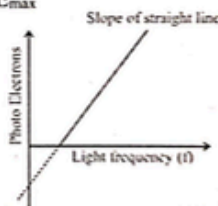
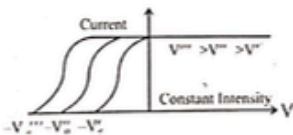
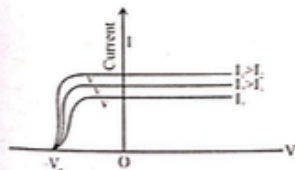
Effect of Potential on Photoelectric Current

- On increasing the potential current first increases and at a fixed potential reaches a maximum value known as saturation current.
- 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.

$$hf = eV + \phi_0 \quad \text{or} \quad hf = K.E + \phi_0 \quad \text{or} \quad \phi_0 = hf - K.E_{\max}$$



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.

$$\phi_0 = hf_0 = \frac{hc}{\lambda_0}$$

- 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_0):** The minimum energy required to eject an electron from the metal surface is known as its work function. $\phi_0 = hf_0$

(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.**

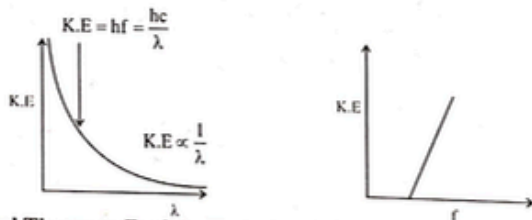
- **Photo sensitive material:** Those elements that eject photons when high frequency light is incident on the material are called photo sensitive material.
- **Saturated photocurrent:** The maximum value of photocurrent is called saturated current.
- Due to stopping potential the work done by electrons is equal to the maximum kinetic energy of electrons. $eV_0 = \frac{1}{2}mv_{\max}^2$

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.

$$E = hf = \frac{hc}{\lambda}$$

Einstein's Photoelectric Equation:

$$K.E._{\max} = hf - \phi_0 = hf - hf_0 = h(f - f_0) \quad , \quad \frac{1}{2}mv_{\max}^2 = hf - \phi_0$$

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.

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**.

$$\Delta\lambda = \lambda_f - \lambda_i$$

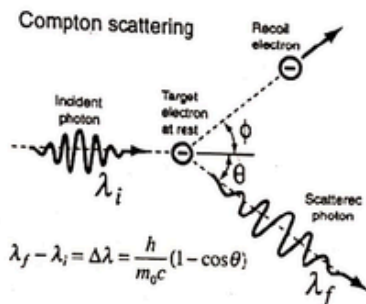
$$\Delta\lambda = \frac{h}{m_0c} (1 - \cos\theta)$$

$\Delta\lambda = \frac{h}{m_0c} = 2.43 \times 10^{-12}$ m is called Compton wavelength.

$\Delta\lambda = 0$ when $\theta = 0^\circ$.

$\Delta\lambda = \frac{h}{m_0c}$ when $\theta = 90^\circ$.

$\Delta\lambda = \frac{2h}{m_0c}$ when $\theta = 180^\circ$.

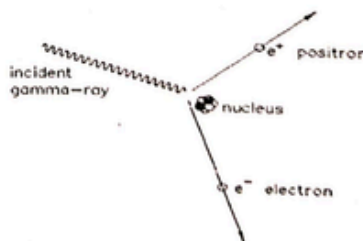


- Photoelectric effect and Compton effect are strong evidences that e.m waves behave as **particle (photon)**.
- Compton effect proves **photon** theory of light.

Pair Production:

Decomposition of photon into electron, positron pair is called pair production.

- Pair production can take place only if photon energy is greater than **1.02 MeV**.
- Energy equation for pair production is given as;
- $hf = 2m_0c^2 + K.E._e^- + K.E._e^+$
- Rest mass energy of electron or positron is m_0c^2 (**= 0.51 MeV**).
- Condition for pair production is that $hf > 2m_0c^2$
- Pair production cannot 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**



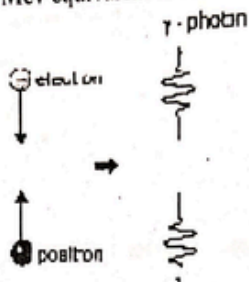
Annihilation of Matter:

Reverse process of pair production is called **annihilation of matter**.

- It involves conversion of mass into energy.

Topic-11

- 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 0.51 MeV 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

CRITICAL CONCEPT!

- What is the reverse process of Photo electric effect?
- What is the reverse process of pair production?

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

$$\lambda = \frac{h}{p} \Rightarrow \lambda \propto \frac{1}{m} \Rightarrow \lambda \propto \frac{1}{v}$$

COURSE CONTENT

- Atomic Spectra/Line Spectrum

ATOMIC SPECTRA / LINE SPECTRUM

Spectrum

Spectrum means set of frequencies absorbed or emitted by a substance.

Types

(a) Emission Spectrum

Set of frequencies emitted by atoms of a substance.

(b) 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

(a) Continuous spectra

It is emitted from condensed matter (solid or liquid). A black body spectrum is continuous spectra

(b) Line spectra

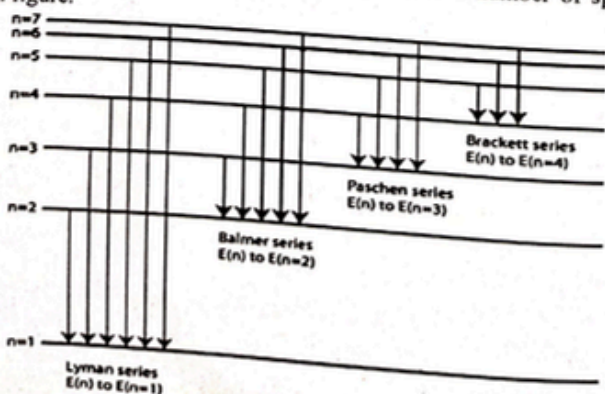
It is emitted by a gas or vapour state of element.

(c) Band spectra

Molecular spectra is band spectra

Spectrum of Hydrogen

Whenever an electron in a hydrogen atom jumps from higher energy level to the lower energy level, the difference of energies of the two levels is emitted as a radiation of particular wavelength. It is called a spectral line. Depending upon the order of their wavelengths, these spectral lines can be grouped into a number of spectral Series as shown in figure.



SERIES	RELATIONS	REGION	LONGEST WAVELENGTH	SHORTEST WAVELENGTH
LYMAN SERIES	$\frac{1}{\lambda} = R \left(\frac{1}{1^2} - \frac{1}{n^2} \right)$ $n = 2, 3, 4, \dots, \infty$	U.V	Put $n=2$ $\lambda = \left(\frac{4}{3R} \right)$	Put $n = \infty$ $\lambda = \frac{1}{R}$
BALMER SERIES	$\frac{1}{\lambda} = R \left(\frac{1}{2^2} - \frac{1}{n^2} \right)$ $n = 3, 4, 5, \dots, \infty$	Visible	Put $n=3$ $\lambda = \frac{36}{5R} =$	Put $n = \infty$ $\lambda = \frac{4}{R}$
PASCHEN SERIES	$\frac{1}{\lambda} = R \left(\frac{1}{3^2} - \frac{1}{n^2} \right)$ $n = 4, 5, 6, \dots, \infty$	Infrared	Put $n = 4$ $\lambda = \frac{144}{7R} =$	Put $n = \infty$ $\lambda = \frac{9}{R}$
BRACKET SERIES	$\frac{1}{\lambda} = R \left(\frac{1}{4^2} - \frac{1}{n^2} \right)$ $n = 5, 6, 7, \dots, \infty$	Infrared	Put $n = 5$ $\lambda = \frac{400}{9R}$	Put $n = \infty$ $\lambda = \frac{16}{R}$
PFUND SERIES	$\frac{1}{\lambda} = R \left(\frac{1}{5^2} - \frac{1}{n^2} \right)$ $n = 6, 7, 8, \dots, \infty$	Infrared	Put $n = 6$ $\lambda = \frac{900}{11R}$	Put $n = \infty$ $\lambda = \frac{25}{R}$

Example: If the wavelength of photon emitted due to transition of electron from third orbit to first orbit in a hydrogen atom is λ , then the wavelength of photon emitted due to transition of electron from fourth orbit to second orbit will be

- A. $\frac{128}{27}\lambda$ B. $\frac{25}{9}\lambda$ C. $\frac{36}{7}\lambda$ D. $\frac{125}{11}\lambda$

Solution: A. $\frac{1}{\lambda} = R \left[\frac{1}{1^2} - \frac{1}{3^2} \right] = R \left[1 - \frac{1}{9} \right] = \frac{8R}{9}$ or $\lambda = \frac{9}{8R}$

Again $\frac{1}{\lambda'} = R \left[\frac{1}{2^2} - \frac{1}{4^2} \right]$

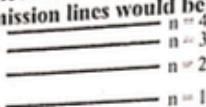
$$\frac{1}{\lambda'} = R \left[\frac{1}{4} - \frac{1}{16} \right] = R \times \frac{3}{16} \Rightarrow \lambda' = \frac{16}{3}R$$

$$\frac{\lambda'}{\lambda} = \frac{16}{3R} \times \frac{8R}{9}$$

$$\lambda' = \frac{128}{27}\lambda$$

CRITICAL THINKING?

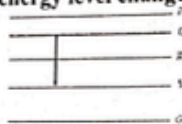
1. Four lowest energy levels of H atom are shown in the figure. The number of possible emission lines would be



A. 3
C. 5

B. 4
D. 6

2. Figure shows the energy levels P, Q, R, S and G of an atom where G is the ground state. A red line in the emission spectrum of the atom can be obtained by an energy level change from Q to S. A blue line can be obtained by following energy level change



A. R to S
C. R to G

B. Q to R
D. P to Q

CRITICAL CONCEPT!

What is the energy of the photon emitted when a hydrogen atom makes a transition from $n = 2$ to $n = 1$ state?

MAIN POINTS OF BOHR'S ATOMIC MODEL:

- An electron can revolve only in those orbits in which their angular momentum is **integral multiple of unit $h/2\pi$** . So, $mV_n r_n = nh/2\pi$
- As long as electron remains in an allowed orbit, its energy remains constant, in spite of fact that continuously it undergoes angular acceleration.
- Emission or absorption of energy from atom takes place only when its electron undergoes down or up transition between two allowed orbits. $\Delta E = E_n - E_p$ or $hf = E_n - E_p$
- Bohr's atomic model produced good results for H-atom and for one-electron atom.

Quantized Radii:

- Radius of n th orbit of the atom is given as;

$$r_n = \frac{n^2 h^2}{4\pi^2 m e^2 k} \quad \text{or} \quad r_n = r_0 n^2$$

where

$$r_0 = \frac{h^2}{4\pi^2 m e^2 k}$$

If $n = 1$ then $r_1 = 0.53 \text{ \AA}$ (Bohr's Radius)
Similarly, $r_2 = 4r_1$ & $r_3 = 9r_1$ and so on.

It shows that radii are **quantized** and they occur in the following ratio:

$$r_1:r_2:r_3:\dots = 1:4:9 \dots$$

Quantized Energy:

Energy of n th level of hydrogen

atom is given by $E_n = -\frac{13.6}{n^2} \text{ eV}$.

Energy associated with first orbit

of the hydrogen atom is

$E_1 = \frac{-13.6}{1^2} = -13.6 \text{ eV}$. It is

called as **ground state energy of**

hydrogen atom. Energy associated

with second orbit is given by

$E_2 = -\left(\frac{13.6}{2^2}\right) = -3.4 \text{ eV}$. It is

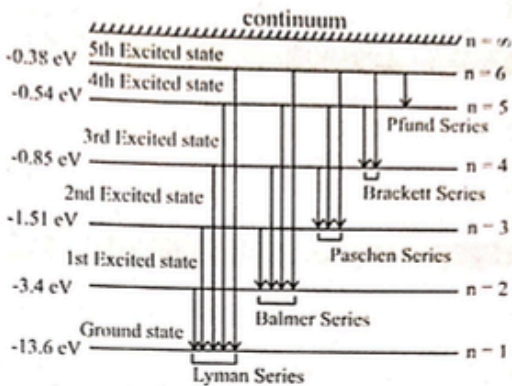
called as energy of **first excited**

state of hydrogen atoms. The energy of second, third, fourth.....excited states of

hydrogen atom are given by

$E_3 = \frac{-13.6}{3^2} = -1.51 \text{ eV}$, $E_4 = -\frac{13.6}{4^2} = -0.85 \text{ eV}$ and when $n = \infty$, $E_\infty = \frac{-13.6}{\infty} = 0 \text{ eV}$

We find that as n increases, the energy associated with a state becomes less negative and approaches closer and closer to the maximum value zero for $n = \infty$. The figure shows the energy level diagram of hydrogen and various spectral series emitted by it.



Excitation potential:

The potential required to raise the electron from ground state to higher state. e.g. for hydrogen, 1st excitation potential = 10.2 eV and 2nd excitation potential = 12.1 eV

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.

LIMITATIONS OF BOHR'S MODEL:

It could not interpret the details of the optical spectra of atoms containing more than one electron.

There was no theoretical basis for selecting the orbits which had an integral multiple of

$$\frac{h}{2\pi}$$

It involves the concept of orbit which could not be checked experimentally.

It failed to explain the line structure of spectral lines.

COURSE CONTENT

- Simple Model for the atom to include protons, neutrons and electrons
- Spontaneous and random nuclear decay/ the Law of Radioactive Decay
- Half Life and rate of decay
- Biological effects of Radiation
- Biological and Medical Uses of Radiation

ATOMIC NUCLEUS

- The nucleus is very small part which exists at the center of the atom.
- Nucleus was discovered by Rutherford through his α -scattering experiments.
- The whole positive charge and almost the whole mass of an atom resides inside the nucleus.
- The charge on the nucleus is $(+Ze)$. It is due to protons present in the nucleus.
- The radius of the nucleus is the order of 10^{-15} to 10^{-14} m.(fermi)
- If the nucleus is presumed to be spherical its radius $r = r_0 A^{\frac{1}{3}}$ where $r_0 = 1.2 \times 10^{-15}$ m and A is atomic number.
- The constituents of nucleus are neutrons and protons. In an atom electron equal in number to protons, revolve round the nucleus.
- In lighter nuclei the proton number equals the neutron number ($N = Z$) e.g. ${}^2_1\text{H}$ etc.
- In heavier nuclei the number of neutrons is greater than the number of protons ($N > Z$) e.g. ${}^{238}_{92}\text{U}$, ${}^{234}_{90}\text{Th}$ etc.
- The neutrons and protons present inside the nucleus taken together are known as nucleons.

Isotopes:

The atoms of an element having same atomic number but different atomic mass number are called isotopes, e.g.

Hydrogen ${}^1_1\text{H}$, ${}^2_1\text{H}$, ${}^3_1\text{H}$ and Oxygen : ${}^{16}_8\text{O}$, ${}^{17}_8\text{O}$, ${}^{18}_8\text{O}$

- The mass numbers (i.e. number of nucleons) of all isotopes of an element are different. Hence their physical properties are not the same.
- Among isotopes of the same element, some may be stable and some radioactive. This is due to difference in their nuclear structure. For example ${}^{12}_6\text{C}$ is stable while ${}^{14}_6\text{C}$ is radioactive similarly ${}^{23}_{11}\text{N}$ is stable while ${}^{24}_{11}\text{Na}$ is radioactive.

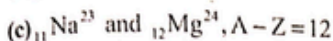
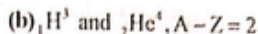
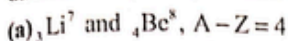
Isobars:

- The nuclei having same number of nucleons (A) but different number of protons (Z) are called isobars. They also have different number of neutrons. For example (a) ${}^3_1\text{H}$ and ${}^3_2\text{He}$ (b) ${}^{14}_6\text{C}$ and ${}^{14}_7\text{N}$ (c) ${}^{17}_8\text{O}$ and ${}^{17}_9\text{F}$

- They differ in chemical properties.
- Isobars differ in physical properties also.
- Nuclei of isobars belong to different elements.
- The daughter nucleus remaining after emission of β -particles is an isobar of the parent nucleus.

Isotones:

The nuclei having equal number of neutrons are called isotones. For them both Z and A are different but $(A - Z)$ is same. For example



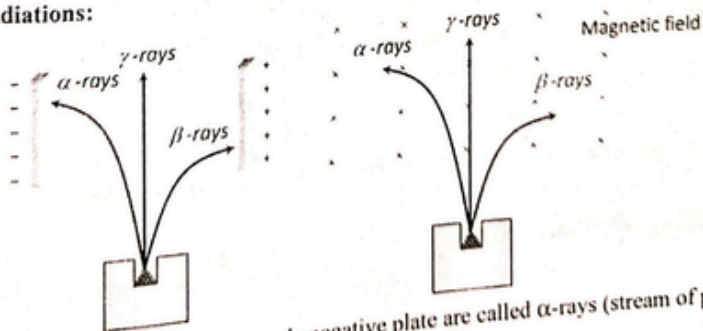
RADIOACTIVITY:

The phenomenon of spontaneous emission of radiations by heavy elements is called radioactivity. The elements which show this phenomenon are called radioactive elements.

- (1) Radioactivity was discovered by Henry Becquerel in uranium salt in the year 1896.
- (2) After the discovery of radioactivity in uranium, Pierre Curie and Madame Curie discovered a new radioactive element called radium (which is 106 times more radioactive than uranium)
- (3) Some examples of radioactive substances are : Uranium, Radium, Thorium, Polonium, Neptunium etc.
- (4) Radioactivity of a sample cannot be controlled by any physical (pressure, temperature, electric or magnetic field) or chemical changes.
- (5) All the elements with atomic number (Z) > 82 are naturally radioactive.
- (6) The conversion of lighter elements into radioactive elements by the bombardment of fast moving particles is called artificial or induced radioactivity.
- (7) Radioactivity is a nuclear event and not atomic. Hence electronic configuration of atom doesn't have any relationship with radioactivity.

- Some radioactive elements are Po ($Z=84$) Rd ($Z=88$) and U ($Z=92$) etc.

Nuclear radiations:



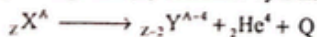
- (i) Radiations which deflect towards negative plate are called α -rays (stream of positively charged particles)
- (ii) Radiations which deflect towards positive plate are called β particles (stream of negatively charged particles)
- (iii) Radiations which are undeflected called γ -rays. (E.M. waves or photons)

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Properties of alpha, beta and Gamma:

Features	α -particles	β -particles	γ -rays
Identity	Helium nucleus or doubly ionized helium atom (${}^4_2\text{He}^{4+}$)	Fast moving electron ($-\beta^0$ or β^+)	Photons (E.M. waves)
Charge	+ 2e	-e	zero
Mass $4 m_p$ ($m_p =$ mass of proton $= 1.87 \times 10^{-27}$)	$4 m_p$	m_e	Massless
Speed	$\approx 10^7$ m/s	1% to 99% of speed of light	Speed of light
Penetration power (γ, β, α)	Low	Medium	high
Ionization power ($\alpha > \beta > \gamma$)	High	Medium	0
Effect of electric or magnetic field	Deflected	Deflected	Not deflected
Energy spectrum	Line and discrete	Continuous	Line and discrete
Equation of decay	${}_Z X^A \xrightarrow{\alpha\text{-decay}} {}_{Z-2} Y^{A-4} + {}_2 \text{He}^4$ ${}_Z X^A \xrightarrow{\beta^+} {}_Z Y^A$ $\Rightarrow n_\alpha = \frac{A' - A}{4}$	${}_Z X^A \rightarrow {}_{Z+1} Y^A + {}_{-1} e^0 + \bar{\nu}$ ${}_Z X^A \xrightarrow{\beta^-} {}_Z Y^A$ $\Rightarrow n_\beta = (2n_\alpha - Z + Z')$	${}_Z X^{A*} \rightarrow {}_Z X^A + \gamma$

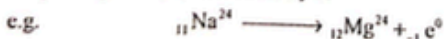
α -decay Charge no. (Z) decreases by 2 and mass no. (A) by 4



β -particle β -particle is electron or positron coming from nucleus. So it may be classified as;

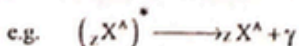


Only charge no. (Z) increases by 1.



Note: Weak interaction only appears in β -decay.

γ -decay: γ -rays are massless photons; their emission will cause no change either in A or Z of the parent nuclide. γ -decay is due to de-excitation of nucleus.



where * sign show excitation of atom

Example: A nucleus of the nuclide ${}_{94}^{241}\text{Pu}$ decays by emission of a β -particle followed by the emission of an α -particle. Which of the nuclides shown is formed?

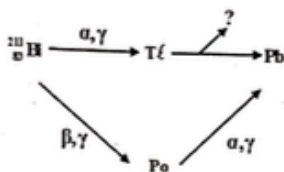


Solution: B. ${}_{94}^{241}\text{Pu} \rightarrow {}_x^y\text{A} + {}_{-1}^0\beta + {}_2^4\text{He}$

$$\begin{cases} 241 = x + 0 + 4 \Rightarrow x = 237 \\ 94 = y + (-1) + 2 \Rightarrow y = 93 \end{cases}$$

CRITICAL THINKING ?

1. Part of the actinium radioactive series can be represented as follows:



What is the particle emitted when Th decays to Pb ?

- A. α -particle
 B. β -particle
 C. One α -particle and two β -particles
 D. Two β -particles

SPONTANEOUS AND RANDOM NUCLEAR DECAY

- Radioactive elements disintegrate and emit α , β and γ radiations. This process is called transmutation by spontaneous disintegration.
- In the natural spontaneous disintegration of a radioactive material not all the atoms disintegrate at the same time.
- The process of disintegration takes place randomly, when a nucleus disintegrates, nobody knows

HALF-LIFE AND RATE OF DECAY

- 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
 - Extremely short half-life $T_{1/2}$ in micro or nano seconds
 - Moderate half-life $T_{1/2}$ in minutes.
 - Long half-life $T_{1/2}$ in years.

Half-life can be given as

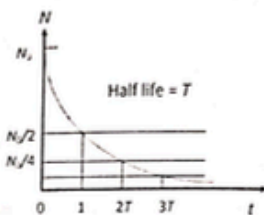
$$\lambda T_{1/2} = \ln 2 = 0.693$$

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

- $\Delta N/\Delta t \propto N_0$
- $\Delta N/\Delta t = -\lambda N_0$
- $N_t = e^{-\lambda t} N_0$
- $T_{1/2} \propto 1/\lambda$
- $\lambda = \frac{-\Delta N/\Delta t}{N}$
- Mean life = $T^* = 1/\lambda$
- $T_{1/2} = T^* (0.693)$



Activity

It is defined as the rate of disintegration (or count rate) of the substance (or the number of atoms of any material decaying per second)

$$\text{i.e. } A = -\frac{\Delta N}{\Delta t} = \lambda N_0 e^{-\lambda t} = A_0 e^{-\lambda t}$$

Where A_0 = Activity of $t = 0$, A = Activity after time t Units of activity (Radioactivity)

Its units are Becquerel (Bq), Curie (Ci) and Rutherford (Rd)

1 Becquerel = 1 disintegration/sec

1 Rutherford = 10^6 dis/sec,

1 Curie = 3.7×10^{10} dis/sec

Note: Activity per gm of a substance is known as specific activity

Time (t)	Number of undecayed atoms (N) (N_0 = Number of initial atoms)	Remaining fraction of active atoms (N/N_0) probability of survival	Fraction of atoms decayed ($(N_0 - N)/N_0$) probability of decay
$t = 0$	N_0	1 (100%)	0
$t = T_{1/2}$	$N_0/2 = N_0/2$	1/2 (50%)	1/2 (50%)
$t = 2T_{1/2}$	$N_0/4 = N_0/4$	1/4 (25%)	3/4 (75%)
$t = 3T_{1/2}$	$N_0/8 = N_0/8$	1/8 (12.5%)	7/8 (87.5%)
$t = 10T_{1/2}$	$N_0/2^{10}$	$(1/2)^{10}$ approx.: 0.1%	Approx.: 99.9%
$t = nT_{1/2}$	$N_0 / 2^n$	$1/2^n$	$1 - (1/2^n)$

Example: The half-life of a certain radioactive element is such that 7/8 of a given quantity decays in 12 days. What fraction remains undecayed after 24 days?

- A. 0 B. $\frac{1}{128}$ C. $\frac{1}{64}$ D. $\frac{1}{32}$

Solution: C. The radioactive element has 1/8 of a given quantity remains after 12 days. After 24 days, or in additional 12 days, the fraction remains undecayed is

$$\left(\frac{1}{8}\right)\left(\frac{1}{8}\right) \text{ or } \frac{1}{64}$$

Useful relation:

$$N = N_0 (1/2)^n = N_0 (1/2)^{t/T_{1/2}}$$

After n half-lives, number of un-decayed atomsMean (or average) life (T_m):

It is defined as the sum of lives of all atoms divided by the total number of atoms

$$T_m = \frac{\text{Sum of the lives of all the atoms}}{\text{Total number of atoms}} = \frac{1}{\lambda}$$

Half Life of some Radioactive Elements

Radioactive Nuclides	Half life
Iodine-131 (I)	8 days
Krypton-86 (Kr)	3.16 minutes
Sodium-24 (Na)	15 hours
Cobalt-60 (Co)	5.27 years
Radium-228 (Ra)	1600 years
Uranium-235 (U)	703 million years
Radium-226 (Ra)	1.6×10^3 years
Uranium-238 (U)	4.5×10^9 years
Plutonium-239	2.4×10^4 years
Radon-220	52 seconds
Strontium-90 (Sr)	28 years
Protactinium (Pa)	6.66 hours
Radon gas	3.8 days
Uranium-239	23.5 minutes

For Your Information:

- Any quantity that decreases by half over equal time intervals is said to decay exponentially.
- Any quantity that increases by twice over equal time interval is said to grow exponentially.

CRITICAL THINKING ?

- The percentage of the original quantity of a radioactive material left after five half-lives is approximately
 - 1 %
 - 5 %
 - 3 %
 - 20 %
- When an animal dies each gram of carbon in its body emits about 16β particles each minute. Each gram of carbon from same animal remains is found to emit 4β particles per minute. How old is the animal (Half-life of radioactive carbon is 6000 years)?
 - 3000 years
 - 6000 years
 - 12000 years
 - 18000 years

BIOLOGICAL AND MEDICAL USES OF RADIATION

Uses of radioactive isotopes:

(1) In medicine:

- For testing blood-chromium - 51
- For testing blood circulation - Na - 24
- For detecting brain tumor- Radio mercury - 203
- For detecting fault in thyroid gland - Radio iodine - 131
- Radiation therapy is a process of destruction of cancerous cells deep into body e.g. Co-60 & I-131 are used to treat cancers.
- For skin diseases - Phosphorous - 31
- β -particle is used for **superficial skin therapy**
- α -particle is used for **deep skin therapy**
- Ratio of C-14 to C-12 found in dead matter is a measure of time span since death.

(2) In Archaeology:

- For determining age of archaeological sample (carbon dating) 14 C
- For determining age of meteorites - 40 K
- For determining age of earth-Lead isotopes

(3) In agriculture:

- For protecting potato crop from earthworm Co-60
- For artificial rains - AgI
- As fertilizers P- 32

(4) As tracers:

- Very small quantity of radioisotopes present in a mixture is known as tracer
- C-14 is one of useful tracer that can help in the understanding of **photosynthesis**.

(5) In industries:

- I-131 and Na-24 are used to check **cracks in pipes**.
- γ radiations 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 radiations 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**
- When ethylene is radiated with γ -rays, it is polymerized into polyethylene, which is used to **produce soft and flexible products**.

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 that they begin to reproduce rapidly leading to a **condition called cancer**.
- Damage to ozone layer is done through following sources: -

(a) Chemical industry	(b) Nuclear tests
(c) CFC (chlorofluorocarbons)	(d) Aerosol sprays and plastic foam industry

- Some radiation in the environment is added by human activities like diagnostic x-ray, luminous watches and tobacco leaves.

EFFECTS OF RADIATIONS:

Effects of radiations are of two types:

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.

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.

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).

$$1 \text{ Gy} = 1 \text{ J kg}^{-1}$$

An old unit is rad, an acronym for radiation absorbed dose. $1 \text{ rad} = 0.01 \text{ Gy}$

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)

$$1 \text{ Sv} = 1 \text{ Gy} \times \text{RBE} \quad (\text{SI Unit})$$

$$\text{Old Unit} \quad 1 \text{ rem} = 0.01 \text{ Sv}$$

BASIC FORCES OF NATURE:

There are now four basic forces in nature.

- Gravitational force (long range)
- Electromagnetic force (long range)
- Strong nuclear force (short range, 10^{-15} m) attractive
- Weak nuclear force (short range, 10^{-17} m) repulsive

In 1979, the physics nobel prize was conferred on Glashow, Weinberg and Abdus Salam for the unification of electromagnetic and weak forces.

BUILDING BLOCKS OF MATTER:

Subatomic particles are divided into three groups

- (a) Photons (b) Leptons (electron, muons and neutrinos) (c) Hadrons

Hadrons:

Particles that interact through the strong force are called hadrons. There are two class of hadrons, known as mesons and baryons. Mesons has mass between the mass of the electron and the mass of proton. All mesons are known to be decay finally into electrons, positrons, neutrinos, and photons. The pion is the lightest of known mesons. Baryons, which are the second class of hadrons, have mass equal to or greater than proton mass. Protons and neutrons are included in the baryon family, as are many other particles with the exception of the proton all baryons decay in such a way that the end products include a proton.

Topic-13

Leptons:

Leptons are a group of particles that participate in the weak interaction. Include in this group are electrons, muons, and neutrinos, which are all less massive than the lightest hadron. Since lepton has no internal structure, they appear to be truly elementary particles. Scientists believe that there are only six leptons.

Quarks:

According to quark theory initiated by M. Gell-Mann and G. Zweig, the quarks are proposed as the basic building blocks of the mesons and baryons. The quark model is based on the following assumptions.

1. There are six different types of quark, the up quark, the down quark, the strange quark, the charmed quark, the bottom quark and the top quark referred to as u, d, s, c, b and t.
2. For every type of quark, there is a corresponding antiquark.
3. Quarks combine in three to form particles like the protons and the neutrons. Anti-quarks also combine in threes to form antiparticles like the antiproton and the antineutron.
4. A meson consists of a quark and an anti-quarks.

In term of the charge of the electron, the u, c and t quarks each carry a charge of $+\frac{2}{3}e$ and

the other three quarks carry a charge of $-\frac{1}{3}e$. An anti-quark carries an equal and opposite charge to its corresponding quark. The symbol for anti-quark is the same as for a quark but with a bar over the top. For example, \bar{d} represents the symbol for a down anti quark. Thus

- A proton is composed of two up quarks and a down quark.
- A neutron consists of an up quark and two down quarks, as shown in fig below.

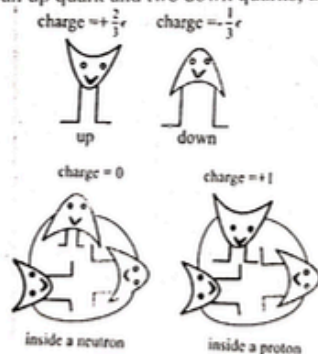


Figure 20.11: up and down quarks illustration

CRITICAL THINKING⁶⁶

4. How many quarks hydrogen atom has?
 A. 1 B. 5
 C. 3 D. 6

Topic - 1

Force and Motion

Displacement (\vec{d}):

$$\Delta \vec{d} = \vec{r}_2 - \vec{r}_1$$

$$\vec{d} = x\hat{i} + y\hat{j}$$

$$d = \sqrt{x^2 + y^2}$$

$$|\vec{d}| \leq s, \quad \frac{|\vec{d}|}{s} \leq 1$$

Units:

metre (m)

Dimensions:

[L]

Velocity:

$$\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$$

$$v_{av} = \frac{\text{Total displacement}}{\text{Total time}} = \frac{\vec{d}}{t}$$

$$\vec{v}_{av} = \lim_{\Delta t \rightarrow 0} \left(\frac{\Delta \vec{d}}{\Delta t} \right)$$

$$v_{av} = \frac{2v_1v_2}{v_1 + v_2} \quad \text{if} \quad (s_1 = s_2)$$

$$v_{av} = \frac{v_1 + v_2}{2} \quad \text{if} \quad (t_1 = t_2)$$

$$v_1 = v_2 = v_{av} \quad \text{if} \quad (v_1 = v_2)$$

Relative velocity:

$$v_r = \sqrt{v_1^2 + v_2^2 - 2v_1v_2 \cos \theta}$$

$$v_r = \sqrt{v_1^2 + v_2^2} \quad (\theta = 90^\circ)$$

$$v_r = v_1 - v_2 \quad (\theta = 0^\circ)$$

$$v_r = v_1 + v_2 \quad (\theta = 180^\circ)$$

Units:

ms^{-1}

Dimensions:

[LT^{-1}]

Acceleration:

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$

$$a_{av} = \frac{v_1 + v_2}{t_1 + t_2} = \frac{a_1t_1 + a_2t_2}{t_1 + t_2}$$

Units:

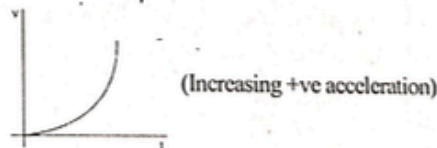
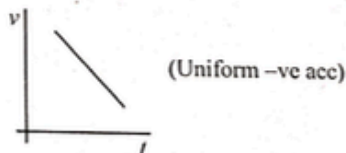
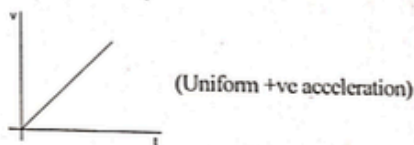
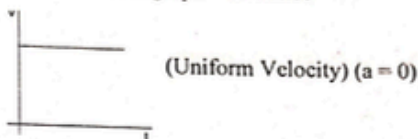
ms^{-2}

Dimensions:

[LT^{-2}]

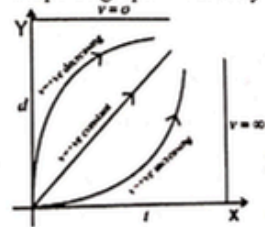
Graphical representation of acceleration with velocity time graph:

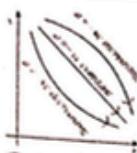
- Slope of graph = Acceleration
- Area under graph = Distance



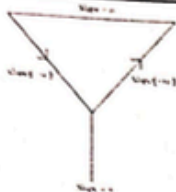
Displacement-time graph:

Slope of graph = velocity





General slope tree:



Newton's laws of motion:

$$F = ma$$

$$\frac{F_1}{F_2} = \frac{a_1}{a_2} \quad (a_1 = a_2)$$

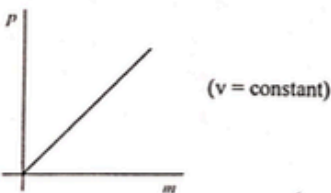
$$\frac{F_1}{F_2} = \frac{m_1}{m_2} \quad (m_1 = m_2)$$

$$\frac{m_1}{m_2} = \frac{a_2}{a_1} \quad (F_1 = F_2)$$

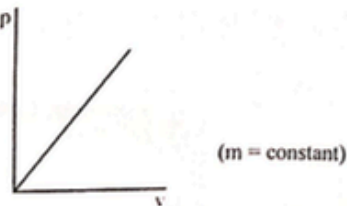
Linear Momentum:

$$p = mv$$

$$p \propto m$$



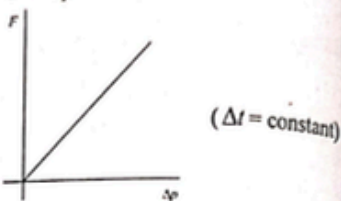
$$p \propto v$$



When body dropped:

$$p = mv = m\sqrt{2gh}$$

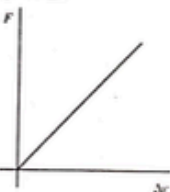
$$F \propto \Delta p$$



$$F = \frac{\Delta p}{\Delta t} = \frac{m\Delta v}{\Delta t}$$

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

$$F \propto \Delta v$$



$$F \times t = m(v_f - v_i) = \text{impulse}$$

$$\frac{F_1}{F_2} = \frac{\Delta p_1}{\Delta p_2}$$

$$P \propto m$$

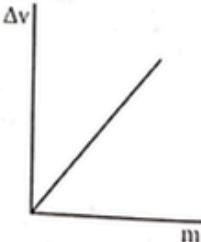
Law of conservation of momentum:

$$m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2'$$

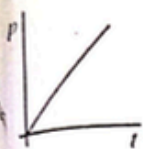
$$\Delta p = 0$$

$$F_{\text{ext}} = \frac{\Delta p}{\Delta t} = 0$$

$$\Delta v \propto m$$



Momentum - time graph:



$$\text{Slop} = \frac{p}{t} = \frac{mv}{t} = \text{Force} = F$$

Projectile Motion:

$$v_{hx} = v_u = v_i \cos \theta$$

$$v_{vy} = v_u - gt$$

$$v_{vy} = v_i \sin \theta - gt$$

$$v_x = \sqrt{v_{hx}^2 + v_{vy}^2}$$

$$v_x = \sqrt{v_i^2 \cos^2 \theta + v_i^2 \sin^2 \theta + g^2 t^2 - 2v_i \sin \theta (gt)}$$

$$v_x = \sqrt{v_i^2 + g^2 t^2 - 2v_i \sin \theta gt}$$

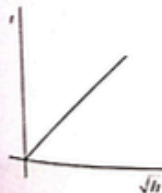
Vertical distance:

$$Y = S = \frac{1}{2}gt^2 = 5t^2$$

$$t = \sqrt{\frac{2h}{g}}$$

$$t = \sqrt{\frac{h}{5}}$$

$$t \propto \sqrt{h}$$



Horizontal distance:

$$x = v_x \times t = v_i \sqrt{\frac{2h}{g}}$$

$$x = v_i \sqrt{\frac{h}{5}}$$

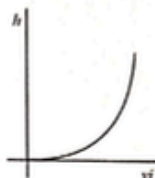
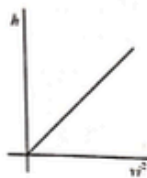
$$x = v_i \sqrt{\frac{h}{5}}$$

Maximum Height:

$$h = \frac{v_i^2 \sin^2 \theta}{2g} = \frac{v_{iy}^2}{2g}$$

$$h \propto \sin^2 \theta$$

$$h \propto v_i^2$$



$$h_{\max} = \frac{v_i^2}{2g}$$

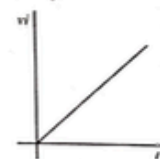
$$h = h_{\max} \sin^2 \theta$$

Time of flight:

$$t = \frac{2v_i \sin \theta}{g} = \frac{2v_{iy}}{g}$$

$$t \propto \sin \theta$$

$$t \propto v_i$$



- Time taken by projectile from place of projection to maximum height.

$$t_1 = \frac{t}{2} = \frac{v_i \sin \theta}{g} = \frac{v_{iy}}{g}$$

- Time taken by projectile from maximum height to place of landing.

$$t_2 = \frac{t}{2} = \frac{v_i \sin \theta}{g}$$

$$t_{\max} = \frac{2v_i}{g}$$

$$t = t_{\max} \sin \theta$$

Horizontal Range:

$$R = t(v_x)$$

$$R = t \times v_x \cos \theta$$

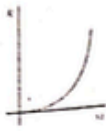
$$R = \frac{v_i^2 \sin^2 2\theta}{g}$$

$$R = \frac{2(v_x \sin \theta)(v_x \cos \theta)}{g}$$

$$R = \frac{2(v_{ix})(v_{ix})}{g}$$

$$R_{\max} \quad (\theta = 45^\circ)$$

$$R \propto v_i^2$$



$$R_{\max} = \frac{v_i^2}{g}$$

$$R = R_{\max} \sin^2 \theta$$

$$R \propto \sin^2 \theta$$

For two angles, if

$$\theta_1 + \theta_2 = 90^\circ \text{ then } R_1 = R_2$$

(If " v_i " for both projectiles is same)

K.E at maximum height:

$$K.E_k = KE_i \cos^2 \theta$$

P.E at maximum height:

$$P.E = KE_i \sin^2 \theta$$

Momentum at maximum height:

$$p_x = p_i \cos \theta$$

$$p_x = mv_i \cos \theta = mv_x$$

Relations between R, H and t:

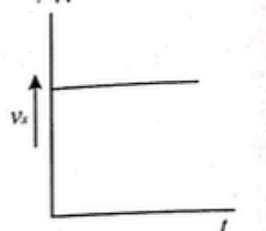
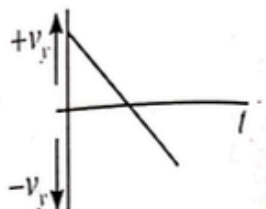
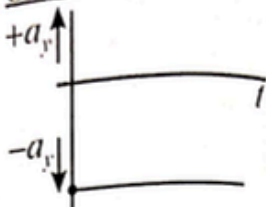
$$R \tan \theta = 4H$$

$$R_{\max} = 4H \quad (\theta = 45^\circ)$$

$$H = \left(\frac{g}{8}\right) t^2$$

$$H \propto t^2$$

Graph:



Topic - 2

Work and Energy

Work:

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

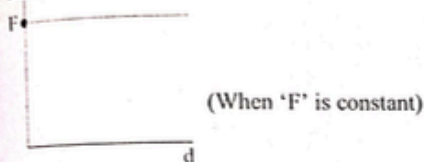
$$W = Fd \cos \theta$$

$$W_{\max} = +Fd \quad (\theta = 0^\circ)$$

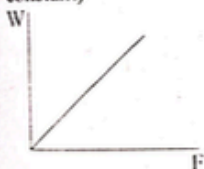
$$W_{\min} = -Fd \quad (\theta = 180^\circ)$$

$$W_{\min} = 0 \quad (\theta = 90^\circ)$$

Graph:



$W \propto F$ (When 'd' & 'θ' are constant)



$W \propto d$
(When 'F' is constant)

Area = $Fd = \text{Work}$

Units:

- joule (S.I unit)
- kilowatt hour (kW h)
- calories (cal)
- erg (c.g.s)
- electron volt (eV)
- 1kW h = 3.6 MJ
- 1cal = 4.18 J
- 1erg = 10^{-7} J
- 1eV = 1.6×10^{-19} J

Dimension:

$$[W] = [M L^2 T^{-2}]$$

Work done by Variables Force:

$$W = F_1 \Delta d_1 \cos \theta_1 + F_2 \Delta d_2 \cos \theta_2 + \dots + F_n \Delta d_n \cos \theta_n$$

$$W = \sum_{i=1}^n F_i \Delta d_i \cos \theta_i$$

Power:

$$P_{\text{av}} = \frac{\Delta W}{\Delta t} = \frac{\vec{F} \cdot \Delta \vec{d}}{\Delta t} = \frac{mgh}{t} = \frac{P.E}{t} = \frac{K.E}{t} = \frac{1/2 mv^2}{t} = \frac{mv^2}{2t}$$

$$P_{\text{inst}} = \lim_{\Delta t \rightarrow 0} \frac{\Delta W}{\Delta t}$$

$$P_{\text{inst}} = \vec{F} \cdot \vec{v}$$

$$= Fv \cos \theta$$

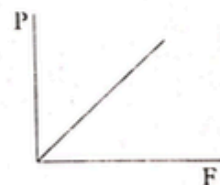
$$P_{\text{inst}} = Fv \quad (\theta = 0^\circ)$$

$$P_{\text{inst}} = -Fv \quad (\theta = 180^\circ)$$

$$P_{\text{av}} = \vec{\tau} \cdot \vec{\omega} = \tau \omega \cos \theta$$

When 'v' & 'θ' are constant

$$P \propto F$$



Energy:

$$G.P.E = mgh$$

$$\text{Elastic P.E} = \frac{1}{2} kx^2$$

$$\text{Electric P.E} = q\Delta V$$

$$K.E = \frac{1}{2} m(\vec{v} \cdot \vec{v}) = \frac{1}{2} mv^2$$

$$K.E \propto v^2 \quad (\text{when } m = \text{constant})$$

Interconversion of K.E and P.E:

In the absence of Air;

Loss in P.E = Gain in K.E

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

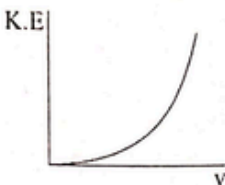
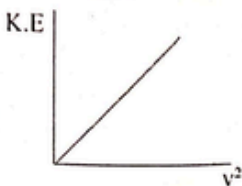
$$\sqrt{2gh} = v$$

In the presence of air;

Loss in P.E = Gain in K.E + Work done against friction

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

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

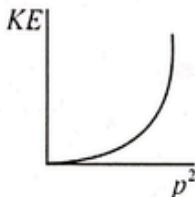


K.E and momentum:

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

$$K.E = \frac{1}{2}pv$$

$$K.E \propto p^2$$



$$\frac{K.E_1}{K.E_2} = \left(\frac{m_2}{m_1}\right)\left(\frac{p_1}{p_2}\right)^2$$

$$\frac{K.E_1}{K.E_2} = \left(\frac{p_1}{p_2}\right)^2 \quad (m = \text{constant})$$

$$p = \sqrt{2m K.E}$$

$$\frac{p_1}{p_2} = \sqrt{\frac{K.E_1}{K.E_2}} \quad (m = \text{constant})$$

$$p \propto \sqrt{K.E}$$

Topic - 3

Rotational and Circular Motion

Angular displacement (Revolution, Degree, Radian):

$$s = r\theta$$

$$r = \frac{s}{\theta}$$

$$\theta = \frac{s}{r}$$

$$1^\circ = 0.0174 \text{ rad}$$

$180^\circ = \pi \text{ rad}$	$1 \text{ rad} = 57.3^\circ$	$1 \text{ rev} = 2\pi \text{ rad}$
-------------------------------	------------------------------	------------------------------------

Angular Velocity:

$$\omega_n = \frac{\Delta\theta}{\Delta t}$$

$$\vec{v} = \vec{\omega} \times \vec{r} = \omega r \sin 90^\circ (\hat{n})$$

$$v = r\omega$$

$$r = \frac{v}{\omega}$$

$$\omega = \frac{v}{r}$$

Units:

- degree/s
- radian/s (S.I unit)
- rev/min

$$1 \text{ rev/min} = \frac{2\pi}{60} \text{ rad/s} = \frac{\pi}{30} \text{ rad/s}$$

Dimensions:

$$[T^{-1}]$$

Angular acceleration:

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

$$\vec{\alpha}_{\text{av}} = \lim_{\Delta t \rightarrow 0} \frac{\Delta\vec{\omega}}{\Delta t}$$

$$\vec{a} = \vec{\alpha} \times \vec{r} = \alpha r \sin 90^\circ (\hat{n})$$

$$a = r\alpha$$

$$r = \frac{a}{\alpha}$$

$$\alpha = \frac{a}{r}$$

Units:

- degrees/s²

- rad/s²
- rev/min²
- $1 \text{ rev/min}^2 = \frac{2\pi}{(60)^2} \text{ rad/s}^2 = \frac{\pi}{1800} \text{ rad/s}^2$

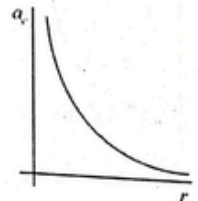
Dimensions:

$$[T^{-2}]$$

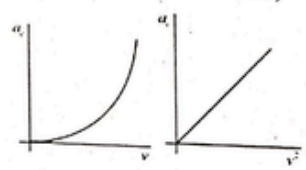
Centripetal acceleration a_c :

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

$$a_c \propto \frac{1}{r} \quad (v = \text{Constant})$$

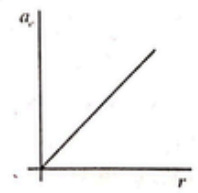


$$a_c \propto v^2 \quad (r = \text{Constant})$$

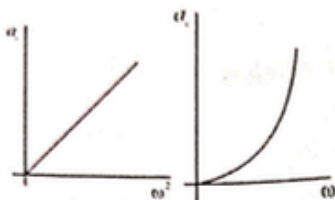


$$a_c = r\omega^2$$

$$a_c \propto r \quad (\omega = \text{Constant})$$



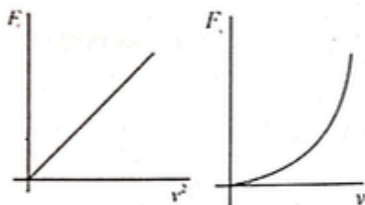
$$a_c \propto \omega^2 \quad (r = \text{Constant})$$



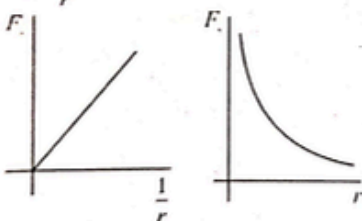
Centripetal force F_c :

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

$$F_c \propto v^2 \quad (r = \text{Constant})$$

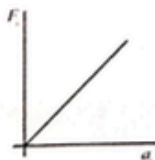


$$F_c \propto \frac{1}{r} \quad (v = \text{Constant})$$



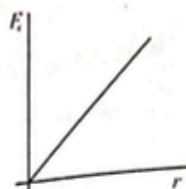
$$F = ma_c$$

$$F_c \propto a_c \quad (m = \text{Constant})$$

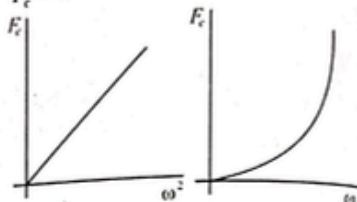


$$F_c = mr\omega^2 \quad \text{or} \quad \vec{F}_c = - (m\omega^2) \vec{r}$$

$$F_c \propto r \quad (\omega = \text{Constant})$$



$$F_c \propto \omega^2 \quad (r = \text{Constant})$$



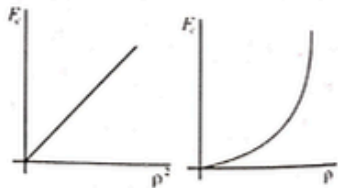
$$F_c = \frac{mv^2}{r}$$

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

$$F_c = \frac{2K.E}{r}$$

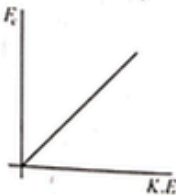
$$F_c = \frac{p^2}{mr}$$

$$F_c \propto p^2 \quad (mr = \text{Constant})$$

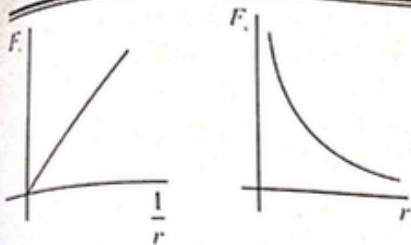


$$F_c = \frac{2K.E}{r}$$

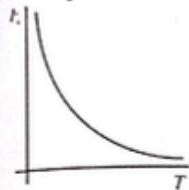
$$F_c \propto K.E \quad (r = \text{Constant})$$



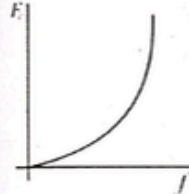
$$F_c \propto \frac{1}{r} \quad (K.E = \text{Constant})$$



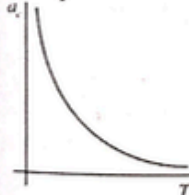
$$F_c = \frac{mr4\pi^2}{T^2}$$



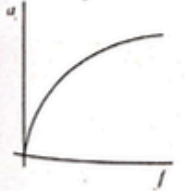
$$F_c = 4\pi^2 mrf^2$$



$$a_c = \frac{4\pi^2 r}{T^2}$$



$$a_c = 4\pi^2 f^2 r$$

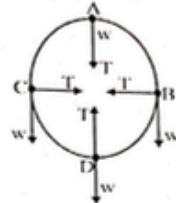


Vertical circle:

Non-uniform circular motion:

$$T = F_c - w \cos \theta$$

$$v = \sqrt{3gr - 2gr \cos \theta}$$



At A:

- $\theta = 0$
- $v = \sqrt{gr}$
- $T_{\min} = F_c - w$

At B:

- $\theta = 90^\circ$
- $v = \sqrt{3gr}$
- $F_c = T$

At D:

- $\theta = 180^\circ$
- $v = \sqrt{5gr}$
- $F_c = T - w$

Note:

- θ is angle between T and w

Horizontal circle:



At A, B, C, D

- $\theta = 90^\circ$
- $F_c = T$
- $v = \sqrt{3gr}$

Topic - 4

Waves

In-phase:

Path difference = $x = n\lambda$

Minimum path difference = $x = 0\lambda$

$n = 0, 1, 2, 3, \dots$

Phase difference = $\phi = \frac{2\pi x}{\lambda}$

$\phi = 0, 2\pi, 4\pi, 6\pi, \dots$

$\phi = 2n\pi$

$\phi_{\min} = 0$

Out of phase:

Path difference = $x = \left(n + \frac{1}{2}\right)\lambda = (2n+1)\frac{\lambda}{2}$

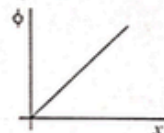
Minimum path difference = $x = \frac{\lambda}{2}$

Phase difference = $\phi = \frac{2\pi x}{\lambda}$

$\phi = \pi, 3\pi, 5\pi, \dots$

$\phi_{\min} = \pi$

$\phi \propto x$



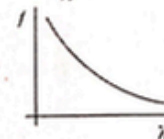
Wave speed v:

$v = f\lambda = \frac{\lambda}{T}$

For same medium,

$\frac{f_1}{f_2} = \frac{\lambda_2}{\lambda_1}$ ($v = \text{constant}$)

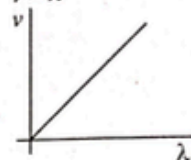
$f \propto \frac{1}{\lambda}$



For different medium,

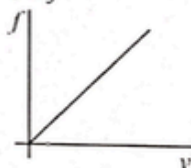
$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$ ($f = \text{constant}$)

$v \propto \lambda$



$\frac{v_1}{v_2} = \frac{f_1}{f_2}$ ($\lambda = \text{constant}$)

$v \propto f$



Principle of superposition:

Interference

$Y_o = y_1 + y_2 + y_3 + \dots + y_n$

In phase	Out phase
$A = a_1 + a_2$	$A = a_1 - a_2$
$I_{\max} = (\sqrt{I_1} + \sqrt{I_2})^2$	$I_{\min} = (\sqrt{I_1} - \sqrt{I_2})^2$
$I_{\max} = (a_1 + a_2)^2$	$I_{\min} = (a_1 - a_2)^2$
If,	If,
$I_1 = I_2 = I$	$I_1 = I_2 = I$
$I_{\max} = 4I$	$I_{\min} = 0$

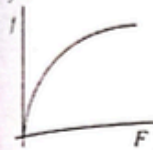
Stationary waves:

	Δx	$\Delta\phi$	Δt
1) N-N	$\frac{\lambda}{2}$	π	$\frac{T}{2}$
2) A-A	$\frac{\lambda}{2}$	π	$\frac{T}{2}$
3) N-A	$\frac{\lambda}{4}$	$\frac{\pi}{2}$	$\frac{T}{4}$

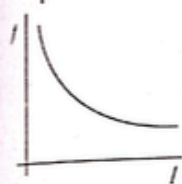
Stationary waves in a stretched string/fundamental frequency and harmonics:

$$f = \frac{v}{2l} = \frac{1}{2l} \sqrt{\frac{F}{m}} \quad \text{Where } m = \frac{\text{mass}}{\text{length}}$$

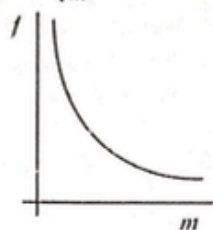
$$f \propto \sqrt{F}$$



$$f \propto \frac{1}{l}$$



$$f \propto \frac{1}{\sqrt{m}}$$



Stationary waves in stretched string or organ pipe open from both ends:

First mode	Second mode	Third mode	n th mode
1 st Harmonics Or Fundamental	2 nd Harmonics Or 1 st Overtone	3 rd Harmonics Or 2 nd Overtone	n th Harmonics Or (n-1) th Overtone
$l = \frac{\lambda_1}{2}$	$l = \lambda_2$	$l = \frac{3}{2} \lambda_3$	$l = n \frac{\lambda_n}{2}$
$\lambda_1 = 2l$	$\lambda_2 = l$	$\lambda_3 = \frac{2}{3} l$	$\lambda_n = \frac{2l}{n}$
$f_1 = \frac{v}{2l}$	$f_2 = \frac{v}{l} = 2f_1$	$f_3 = \frac{3v}{2l} = 3f_1$	$f_n = n f_1$ $n = 1, 2, 3, \dots$
2N, 1A	3N, 2A	4N, 3A	No. of Nodes > A
<ul style="list-style-type: none"> No of nodes = no. of loops + 1 No of antinodes = no. of loops 			

Organ pipe closed from one end:

First mode	Second mode	3 rd mode	n th mode
1 st Harmonics Or Fundamental	2 nd harmonics Or 1 st Over tone	3 rd Harmonics Or 2 nd Over tone	n th Harmonics Or (n-1) th Over tone
$l = \frac{\lambda_1}{4}$	$l = \frac{3\lambda_2}{4}$	$l = \frac{5}{4}\lambda_3$	$l = n \frac{\lambda_n}{4}$ $n = 1, 3, \dots$
$\lambda_1 = 4l$	$\lambda_2 = \frac{3}{4}l$	$\lambda_3 = \frac{4}{5}l$	$\lambda_n = \frac{4l}{n}$ $n = 1, 3, \dots$
$f_1 = \frac{v}{4l}$	$f_2 = 3 \frac{v}{4l} = 3f_1$	$f_3 = 5 \frac{v}{4l} = 5f_1$	$f_n = nf_1$ $n = 1, 3, \dots$
N, A	2N, 2A	3N, 3A	Nodes = Anti nodes

$$f_{open} = 2f_{closed}$$

$$f_{closed} = \frac{f_{open}}{2}$$

Doppler's effect:
General formula:

$$f' = \left(\frac{v \pm u_o}{v \pm u_s} \right) f \quad \text{or} \quad \lambda' = \left(\frac{v \pm u_s}{v \pm u_o} \right) \lambda$$

- Direction of v always towards observer.
- If u_o and u_s along v, then u_o and u_s taken as negative.
- If u_o and u_s opposite to v, then u_o and u_s taken as positive.

1) When observer moves towards stationary source:

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

2) When observer moves away from stationary source:

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

3) When source moves towards stationary observer:

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

4) When source moves away from stationary observer:

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

5) When source and observer are moving towards each other:

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

6) When source and observer are moving away from each other:

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

7) When observer follows source moving in same direction:

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

8) When source follows observer moving in same direction:

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

Simple Pendulum:

$$\omega = \sqrt{\frac{g}{l}}$$

$$F_r = -mg \sin \theta$$

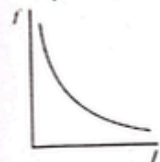
And $T = 2\pi \sqrt{\frac{l}{g}}$

$$T \propto \sqrt{l}$$



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

$$f \propto \frac{1}{\sqrt{l}}$$



Simple Pendulum,

$$T = 1 \text{ sec}$$

$$f = 1 \text{ Hz}$$

$$l = 0.25 \text{ m}$$

Second Pendulum:

$$T = 2 \text{ sec}$$

$$f = 0.5 \text{ Hz}$$

$$l = 0.99 \text{ m}$$

Lift cases:

Lift is at rest or moving with uniform

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

Lift is moving upward with uniform

acceleration: $T = 2\pi \sqrt{\frac{l}{g+a}}$

Lift is moving downward with uniform

acceleration:

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

Lift is moving freely:

$$T = 2\pi \sqrt{\frac{l}{0}} = \infty$$

$$f = \frac{1}{T} = \frac{1}{\infty} = 0 \text{ Hz}$$

Energy Conservation in S.H.M:

P.E:

$$P.E_{\text{max}} = \frac{1}{2} kx^2 = \frac{1}{2} (\omega^2 m) x^2 = \frac{1}{2} (2\pi f)^2 m x^2 = \frac{1}{2} (4\pi^2 f^2) m x^2$$

$$P.E_{\text{min}} = T.E \frac{x^2}{x^2}$$

$$P.E_{\text{min}} = 0 \quad (x=0)$$

$$P.E_{\text{max}} = \frac{1}{2} kx^2 \quad (x=x)$$

K.E:

$$K.E_{\text{min}} = \frac{1}{2} kx^2 \left(1 - \frac{x^2}{x^2}\right)$$

$$K.E_{\text{min}} = T.E \left(1 - \frac{x^2}{x^2}\right)$$

$$K.E_{\text{min}} = 0 \quad (x=x)$$

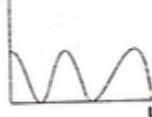
$$K.E_{\text{max}} = \frac{1}{2} kx^2 \quad (x=0)$$

Total Energy:

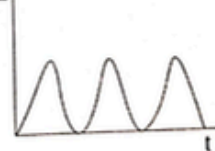
$$T.E = K.E + P.E$$

$$T.E = \frac{1}{2} kx_0^2$$

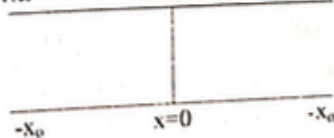
K.E

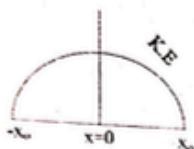
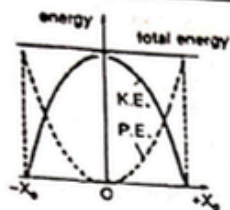


P.E



T.E





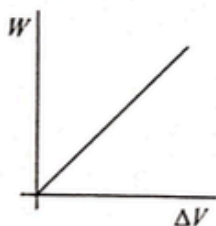
Topic - 5

Thermodynamics

Work and Heat:

$$W = P\Delta V$$

$$W \propto \Delta V$$



First law of thermodynamics:

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

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


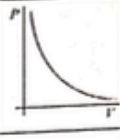
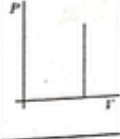
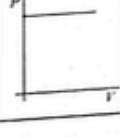
$$W = \Delta Q - \Delta U$$

Molar Specific Heat of a gas:

- C_p is greater in value than C_v ($C_p > C_v$)
- $\Delta Q_v = nC_v\Delta T$ (Heat supplied at constant volume)
- $\Delta Q_p = nC_p\Delta T$ (Heat supplied at constant pressure)
- $C_p - C_v = R$

• $\frac{C_p}{C_v} = \gamma$	• $C_v = \frac{3}{2}R$ (Monoatomic)
• $C_v = \frac{5}{2}R$ (Diatomic)	• $C_v = \frac{7}{2}R$ (Polyatomic)

Comparison of different thermodynamically process:

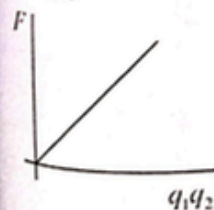
	Condition	Formula	1 st law	P-V diagram	Slope(m)	Specific heat(c)
Isothermal	$T = \text{constant}$ $\Delta T = 0$ $\Delta U = 0$	$PV = \text{constant}$	$Q = \Delta U + W$ $\Delta U = 0$ $Q = W$		Gradually Decreases	$\Delta Q = cm\Delta T$ $c = \frac{\Delta Q}{m\Delta T}$ $\Delta T = 0$ $c = \infty$
Adiabatic	$\pm Q = 0$	$PV^\gamma = \text{constant}$ $\gamma = \frac{C_p}{C_v}$	$Q = \Delta U + W$ $Q = 0$ $0 = \Delta U + W$ $-\Delta U = +W$		Rapidly decreases	$c = \frac{\Delta Q}{m\Delta T}$ $c = 0$
Isochoric	$V = \text{constant}$ $\Delta V = 0$	$\frac{P}{T} = \text{constant}$	$Q = \Delta U + W$ $Q = \Delta U + P\Delta V$ $\Delta V = 0$ $Q = \Delta U$ $\Delta U = nC_v\Delta T$		∞	$c = C_v$
Isobaric	$P = \text{constant}$ $\Delta P = 0$	$\frac{V}{T} = \text{constant}$ $V \propto T$	$Q = \Delta U + W$ $Q = \Delta U + P\Delta V$ $Q = nC_p\Delta T$		0	$c = C_p$

Topic - 6
Electrostatics

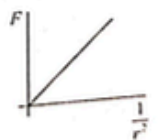
Coulomb's law:

$$F = k \frac{q_1 q_2}{r^2}$$

$$F \propto q_1 q_2$$



$$F \propto \frac{1}{r^2}$$



$$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$$

$$F_{\text{vac}} = \frac{1}{4\pi\epsilon_0} \times \frac{q_1 q_2}{r^2}$$

$$F_{\text{med}} = \frac{1}{4\pi\epsilon_0 \epsilon_r} \times \frac{q_1 q_2}{r^2}$$

$$\epsilon_r = \frac{F_{\text{vac}}}{F_{\text{med}}}$$

$$\epsilon_r = 1 \quad (\text{For vacuum})$$

$$\epsilon_r = 1.0006 \quad (\text{for air})$$

$$\epsilon_r > 1 \quad (\text{always})$$

- ϵ_r has no units.

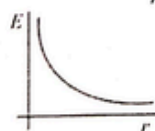
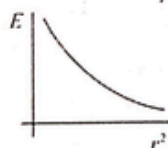
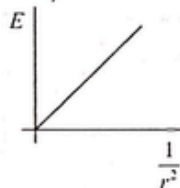
Vector Form of Coulomb's force:

$$\vec{F} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}$$

Electric field intensity \vec{E} :

$$\vec{E} = \frac{\vec{F}}{q} = K \frac{q}{r^2} \hat{r}$$

$$E \propto \frac{1}{r^2}$$



Units:

$$E = \text{NC}^{-1} \text{ or } \text{Vm}^{-1}$$

Potential difference ΔV :

$$\Delta V = \frac{\Delta W}{\Delta q} = \frac{\Delta U}{\Delta q} = \frac{K.E}{\Delta q}$$

$$\Delta W = \Delta U = K.E = q\Delta V$$

Units

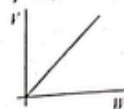
$$\text{volt} = \frac{\text{joule}}{\text{coulomb}}$$

$$V = J \text{ C}^{-1}$$

Electric potential:

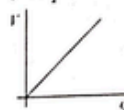
$$V = \frac{W}{q}$$

$$V \propto W$$

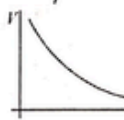


$$V = K \frac{q}{r}$$

$$V \propto q$$



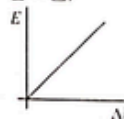
$$V \propto \frac{1}{r}$$



Electric field as potential gradient:

$$\Delta V = \frac{\Delta W}{q} = \frac{\vec{F} \cdot \vec{d}}{q}$$

$$E \propto \Delta V$$

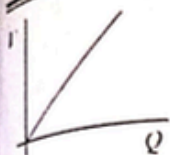


Capacitor:

$$Q = CV$$

$$C = \frac{Q}{V}$$

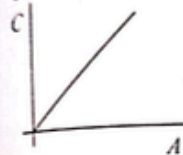
$$Q \propto V$$


Capacitance of parallel plates capacitors:

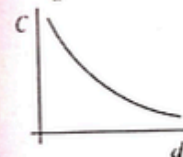
$$C_{vac} = \frac{A\epsilon_0}{d}$$

$$C_{med} = \frac{A\epsilon_0\epsilon_r}{d}$$

$$C \propto A$$



$$C \propto \frac{1}{d}$$



$$\epsilon_r = \frac{C_{med}}{C_{vac}}$$

$$\epsilon_r = \frac{V_{vac}}{V_{med}}$$

Units:

$$c = \frac{\text{coulomb}}{\text{volt}}$$

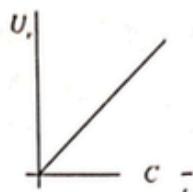
$$c = \text{farad (F)}$$

$$F = CV^{-1}$$

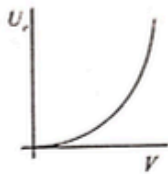
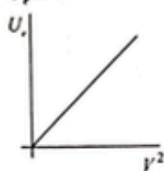
Energy stored in a capacitor:

$$U_s = \frac{1}{2} CV^2$$

$$U_s \propto C$$



$$U_s \propto V^2$$



$$U_s = \frac{1}{2} CV^2$$

$$U_s = \frac{1}{2} QV$$

$$U_s = \frac{Q^2}{2C}$$

$$\text{Energy} = \frac{1}{2} \epsilon_0 \epsilon_r E^2 (Al)$$

$$\text{Energy density} = \frac{\text{Energy}}{\text{Volume}} = \frac{1}{2} \epsilon_0 \epsilon_r E^2$$

$$\text{Energy density} = \frac{1}{2} \epsilon_0 \epsilon_r \frac{V^2}{d^2}$$

Charging & discharging:

$$RC = \text{constant}$$

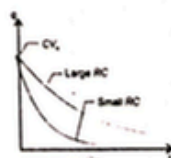
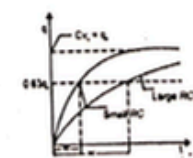
$$RC = \text{time}$$

$$RC = t$$

$$\text{ohm} \times \text{farad} = \text{second}$$

$$q = q_0 (1 - e^{-t/RC})$$

$$q = q_0 e^{-t/RC}$$

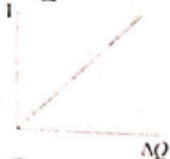


Topic - 7

Current Electricity

Electric Current:

$$I = \frac{\Delta Q}{\Delta t}$$



$$Q = ne$$

$$I = \frac{ne}{\Delta t}$$

Unit

ampere (A)

$$A = Cs^{-1}$$

Drift velocity:

$$v_d = \frac{I}{neA}$$

n = electron density

$$v_d = 10^{-3} \text{ m (for metals)}$$

Dimensions:

[A]

OHM'S Law

$$V = IR$$

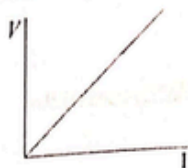
$$I = \frac{V}{R}$$

$$R = \frac{V}{I}$$

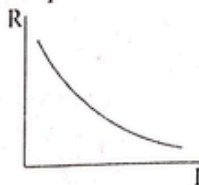
$$V \propto R \quad (\text{keeping } I \text{ constant})$$



$$V \propto I \quad (\text{keeping } R \text{ constant})$$



$$R \propto \frac{1}{I} \quad (\text{keeping } V \text{ constant})$$



Unit of R:

Ohm (Ω)

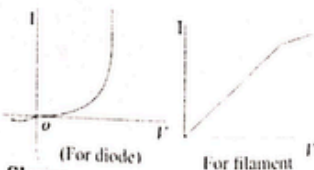
Ohmic conductors:

For metals,

$$I \propto V$$



Non Ohmic conductors:



Slopes



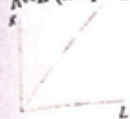
$$\text{Slope of } I-V \text{ Graph} = \sigma = \frac{1}{\tan \theta} = \cot \theta$$



Slope of $V-I$ Graph = $R = \tan \theta$
Specific resistance or resistivity:

$$R = \rho \frac{L}{A}$$

$R \propto L$ (keeping A constant)



$R \propto \frac{1}{A}$ (keeping L constant)

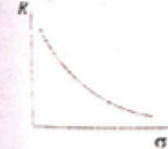


$$\rho = \frac{RA}{L}$$

Units:
 Ωm

$$\text{Resistance (R)} = \frac{1}{\text{conductance}} = \frac{1}{\sigma}$$

$$R \propto \frac{1}{\sigma}$$



$$\text{conductance} = \sigma = \frac{1}{\text{resistance (R)}}$$

Units:

mho or Siemen or Ω^{-1} or \mathcal{U}

$$\text{conductivity} \propto \frac{1}{\text{Resistivity}}$$

$$\sigma = \frac{1}{\rho}$$

Units:

$\text{ohm}^{-1} \text{m}^{-1}$ or mho m^{-1}

Temperature coefficient of resistance

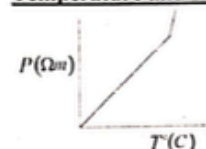
$$\alpha = \frac{R_t - R_0}{R_0 t}$$

$$\alpha = \frac{\rho_t - \rho_0}{\rho_0 t}$$

Units:

$$K^{-1} \text{ or } \frac{1}{K}$$

Temperature and resistivity:



Approximately ohmic

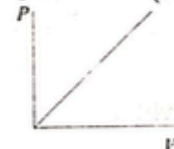
Electric power:

Work done by battery = $\Delta W = V \times \Delta Q$

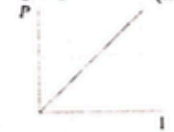
$$P = \frac{\Delta W}{t} = V \frac{\Delta Q}{\Delta t}$$

$$P = VI$$

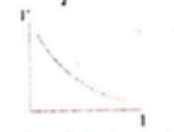
$P \propto V$ (keeping I constant)



$P \propto I$ (keeping V constant)



$V \propto \frac{1}{I}$ (keeping I constant)



Possible formulas:

$$P = I^2 R$$

$P \propto I^2$ (keeping R constant)



$P \propto R$ (keeping I constant)



$P = \frac{I^2}{R}$
 $P \propto I^2$ (keeping R constant)



$P \propto \frac{1}{R}$ (keeping V constant)



Internal resistance of supply:

$$\text{Emf } E = \frac{\Delta V}{\Delta Q}$$

Units

- volt
- 1 volt = $\frac{1 \text{ joule}}{1 \text{ coulomb}}$

Cases:

i. Open circuit:

$$E = IR + Ir$$

$$E = IR = V_r \quad (I = 0)$$

ii. Discharging:

$$E = V_r + Ir$$

$$E > V_r$$

iii. Charging:

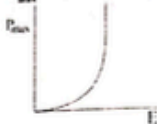
$$E = V_r - Ir$$

$$E < V_r$$

Maximum power output:

$$P_{\text{out(max)}} = \frac{E^2}{4r} = \frac{E^2}{4R}$$

$$P_{\text{max}} \propto E^2 \quad (\text{keeping } R \text{ constant})$$



Brightness of bulbs:

Series combination:

$$\text{Brightness} \propto P_{\text{consumed}}$$

$$\text{Brightness} \propto I^2 R$$

$$\text{Brightness} \propto R$$

$$P_{\text{rated}} = \frac{V_{\text{rated}}^2}{R}$$

$$P_{\text{rated}} \propto \frac{1}{R}$$

Parallel combination:

$$\text{Brightness} \propto P_{\text{consumed}}$$

$$\text{Brightness} \propto \frac{V^2}{R}$$

$$\text{Brightness} \propto \frac{1}{R}$$

$$P_{\text{rated}} \propto \frac{1}{R}$$

Topic - 8

Electromagnetism

Magnetic flux & flux density:

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

$$\phi_B = BA \cos \theta$$

$$\phi_{B_{\max}} = BA \quad (\theta = 0^\circ)$$

$$\phi_{B_{\min}} = -BA \quad (\theta = 180^\circ)$$

$$\phi_B = \frac{\phi_{\max}}{2} = +\frac{BA}{2} \quad (\theta = 60^\circ)$$

$$\phi_B = \frac{\phi_{\max}}{\sqrt{2}} \quad (\theta = 45^\circ)$$

$$\phi_B = \frac{\sqrt{3}BA}{2} \quad (\theta = 30^\circ)$$

$$\phi_{B_{\min}} = 0 \quad (\theta = 90^\circ)$$

$$\text{Flux density} = B = \frac{\phi_m}{A}$$

Units:

$$B = \frac{\text{weber}}{\text{meter}^2} = \text{Wb m}^{-2}$$

$$B = \text{NA}^{-1} \text{m}^{-1} = 1\text{T}$$

Force acting on a charge particle in a uniform magnetic field:

$$\vec{F} = q(\vec{v} \times \vec{B}) = \pm e(\vec{v} \times \vec{B})$$

$$F = qvB \sin \theta$$

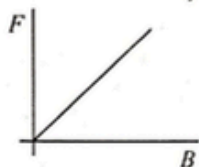
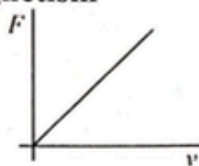
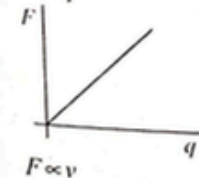
$$B = \frac{F}{qv \sin \theta}$$

$$F_{\max} = qvB \quad (\theta = 90^\circ)$$

$$F_{\min} = 0 \quad (\theta = 0^\circ \text{ or } 180^\circ)$$

$$F = \frac{F_{\max}}{2} \quad (\theta = 30^\circ)$$

$$F \propto q$$



Path followed by charge particle in magnetic field:

If angle between \vec{v} and \vec{B} .

$\theta = 0^\circ / 180^\circ$ path is straight line.

$\theta = 90^\circ$ path is circle.

$90^\circ < \theta < 180^\circ$ path is helical.

$180^\circ < \theta < 90^\circ$ path is helical.

$$F \propto B$$

Charged particle in electric and magnetic field:

$$\vec{a} = \frac{e}{m} \vec{E}$$

Lorentz force

$$\vec{F} = \vec{F}_E + \vec{F}_B$$

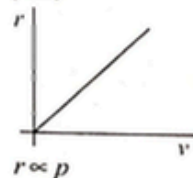
$$\vec{F} = q\vec{E} + q(\vec{v} \times \vec{B})$$

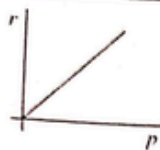
$$\vec{F} = q[\vec{E} + (\vec{v} \times \vec{B})]$$

Charge to mass ratio $\frac{e}{m}$:

$$r = \frac{mv}{qB} = \frac{P}{qB}$$

$$r \propto v$$





$$\omega = \frac{q}{m} B$$

$$f = \frac{qB}{2\pi m}$$

$$T = \frac{2\pi m}{qB}$$

$$v = \frac{E}{B}$$

$$\frac{c}{m} = \frac{2v}{B^2 r^2} = \frac{E}{B^2 r}$$

$$\left(\frac{e}{m}\right)_{\text{electron}} = 1.75 \times 10^{-11} \text{ C kg}^{-1}$$

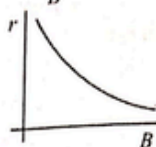
$$\left(\frac{e}{m}\right)_{\text{Proton}} = 1.0 \times 10^{-8} \text{ C kg}^{-1}$$

$$\left(\frac{e}{m}\right)_{\text{neutron}} = 0$$

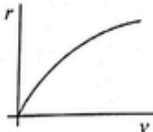
$$r^2 = \frac{2Vm}{B^2 e}$$

$$r = \sqrt{\frac{2Vm}{B^2 e}}$$

$$r \propto \frac{1}{B} \quad (\psi = \text{constant})$$

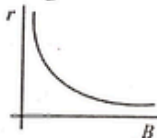


$$r \propto \sqrt{V} \quad (B = \text{constant})$$

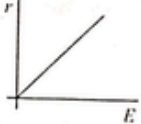


$$r = \frac{Em}{eB^2}$$

$$r \propto \frac{1}{B^2} \quad (E = \text{constant})$$



$$r \propto E \quad (B = \text{constant})$$



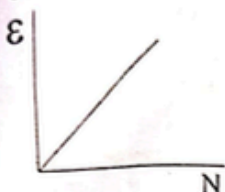
Topic - 9 Electromagnetic Induction

Faraday's Law:

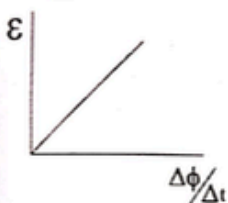
$$\mathcal{E} = -N \frac{\Delta\phi}{\Delta t}$$

$$\mathcal{E} = -\frac{NB\Delta A}{\Delta t} = \frac{NB\pi r^2}{\Delta t} \text{ (for Circular Coil)}$$

$$\mathcal{E} \propto N$$



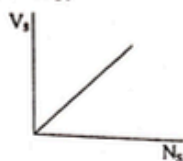
$$\mathcal{E} \propto \frac{\Delta\phi}{\Delta t}$$



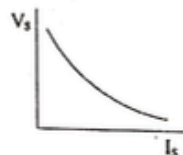
Transformer:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

$$V \propto N$$



$$V_s \propto \frac{1}{I_s}$$



Ideal Transformer:

$$P_{input} = P_{output}$$

$$V_p I_p = V_s I_s$$

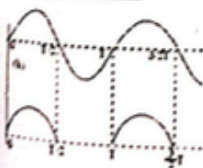
$$\text{Efficiency} = \eta = \frac{\text{output}}{\text{input}} = \frac{P_o}{P_i} = \frac{V_s I_s}{V_p I_p} \times 100\%$$

Topic - 10

Electronics

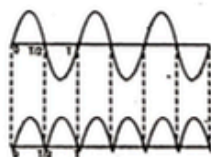
Rectification:

i. Half wave:



$$f_{input} = f_{output}$$

ii. Full wave:



$$f_{input} = 2(f_{output})$$

For filtration capacitor filter is used

Topic - 11

Dawn of Modern Physics

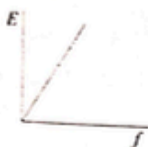
Photons:

$$E = mc^2$$

$$E = pc$$

$$E = hf$$

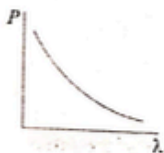
$$E \propto f$$



$$E = \frac{hc}{\lambda}$$

$$p = \frac{h}{\lambda}$$

$$p \propto \frac{1}{\lambda}$$

**Wave nature of particle:**

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$$p = \sqrt{2mE} = \sqrt{2meV}$$

$$\lambda = \frac{h}{\sqrt{2mV}}$$

$$\lambda = \frac{h}{\sqrt{2mK.E}}$$

$$\lambda \propto \frac{1}{\sqrt{E}} \quad (m = \text{constant})$$

$$\lambda \propto \frac{1}{\sqrt{m}} \quad (E = \text{constant})$$

$$\lambda \propto \frac{1}{\sqrt{e}} \quad (m, V \text{ are constant})$$

$$\lambda \propto \frac{1}{\sqrt{V}} \quad (\text{for same charges})$$

Determination of no. of photons

$$E_n = nhf$$

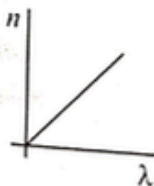
n = number of photons

$$n = \frac{E_n}{hf}$$

$$n = \frac{E\lambda}{hc} \because f = \frac{c}{\lambda}$$

$$\frac{E}{hc} = \text{Constant}$$

$$n \propto \lambda$$



Topic - 12

Atomic spectra

Spectral Series $\rightarrow \frac{1}{\lambda} = R_H \left(\frac{1}{p^2} - \frac{1}{n^2} \right)$

Series	Formula	Region	Longest Wavelength	Shortest Wavelength
Lyman series	$\frac{1}{\lambda} = R_H \left(\frac{1}{1^2} - \frac{1}{n^2} \right)$ $n = 2, 3, 4, \dots, \infty$	U-V	Put $n = 2$ $\lambda = \frac{4}{3R_H}$	Put $n = \infty$ $\lambda = \frac{1}{R_H}$
Balmer series	$\frac{1}{\lambda} = R_H \left(\frac{1}{2^2} - \frac{1}{n^2} \right)$ $n = 3, 4, 5, \dots, \infty$	Visible	Put $n = 3$ $\lambda = \frac{36}{5R_H}$	Put $n = \infty$ $\lambda = \frac{4}{R_H}$
Paschen series	$\frac{1}{\lambda} = R_H \left(\frac{1}{3^2} - \frac{1}{n^2} \right)$ $n = 4, 5, 6, \dots, \infty$	I.R	Put $n = 4$ $\lambda = \frac{144}{7R_H}$	Put $n = \infty$ $\lambda = \frac{9}{R_H}$
Bracket series	$\frac{1}{\lambda} = R_H \left(\frac{1}{4^2} - \frac{1}{n^2} \right)$ $n = 5, 6, 7, \dots, \infty$	I.R	Put $n = 5$ $\lambda = \frac{400}{9R_H}$	Put $n = \infty$ $\lambda = \frac{16}{R_H}$
Pfund series	$\frac{1}{\lambda} = R_H \left(\frac{1}{5^2} - \frac{1}{n^2} \right)$ $n = 6, 7, \dots, \infty$	I.R	Put $n = 6$ $\lambda = \frac{900}{11R_H}$	Put $n = \infty$ $\lambda = \frac{25}{R_H}$

 $R_H = \text{Rydberg's constant} = 1.0974 \times 10^7 \text{ m}^{-1}$

No. of transitions = $\frac{n(n-1)}{2}$

Or

No. of spectral series for n^{th} state = $\frac{n(n-1)}{2}$

 $n = \text{higher energy state}$

Ratio = $\frac{\lambda_{\text{Longest}}}{\lambda_{\text{Shortest}}} = \frac{n^2}{n^2 - p^2}$

 $p = \text{lower energy state}$

$n = p + 1$

Topic - 13

Nuclear Physics

To find no of neutron in a nucleus

$$\Rightarrow N = A - Z$$

Radius of nucleus:

$$r = r_0 A^{1/3} \Rightarrow r^3 \propto A$$

$$r_0 = 1.2 \text{ fm}$$

Volume of nucleus:

$$V = \frac{4}{3} \pi r^3$$

$$V \propto r^3$$

$$V \propto A$$

Radioactivity:

α -decay	β -decay	γ -decay
${}^A_Z X \rightarrow {}^{A-4}_{Z-2} Y + {}^4_2 \text{He}$	${}^A_Z X \rightarrow {}^A_{Z+1} Y + {}^0_{-1} e$	${}^A_Z X \rightarrow {}^A_Z Y + \gamma$
${}^{226}_{88} \text{Ra} \rightarrow {}^{222}_{86} \text{Rn} + {}^4_2 \text{He}$	${}^{234}_{90} \text{Th} \rightarrow {}^{234}_{91} \text{Pa} + {}^0_{-1} e$	

Dependence:

Radioactivity is purely nuclear phenomenon, does not depend on temperature, pressure, electric field & magnetic field.

Half-life:

$$\Delta N = -\lambda N \Delta t$$

$$\lambda = \frac{\Delta N}{N \Delta t}$$

Decay constant:

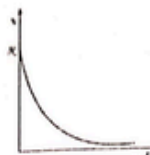
$$N = N_0 e^{-\lambda t} \Rightarrow \frac{N}{N_0} = e^{-\lambda t}$$

$$N = N_0 \left(\frac{1}{2} \right)^n$$

n = no of half-lives

$$\frac{N}{N_0} = \frac{1}{2^n}$$

$$\Delta N \propto N$$



Graph follows this equation $N = N_0 e^{-\lambda t}$

It is exponential decay.

For decay rate (Activity)

$$A = A_0 e^{-\lambda t}$$

Relation between λ & $T_{1/2}$

$$\lambda = \frac{0.693}{T_{1/2}}$$

$$T_{1/2} = \frac{0.693}{\lambda}$$

This graph is for I-128

$$\lambda T_{1/2} = 0.693$$

Mean lifetime:

$$T_{\text{mean}} = \frac{1}{\lambda} = \frac{T_{1/2}}{\ln 2} = \frac{T_{1/2}}{0.693}$$

$$T_{\text{mean}} \propto T_{1/2}$$

$$T_{\text{mean}} \propto \frac{1}{\lambda}$$

For carbon dating

$$t = \frac{1}{\lambda} \ln \left(\frac{N_0}{N} \right)$$

Absorbed dose:

$$D = \frac{E}{m}$$

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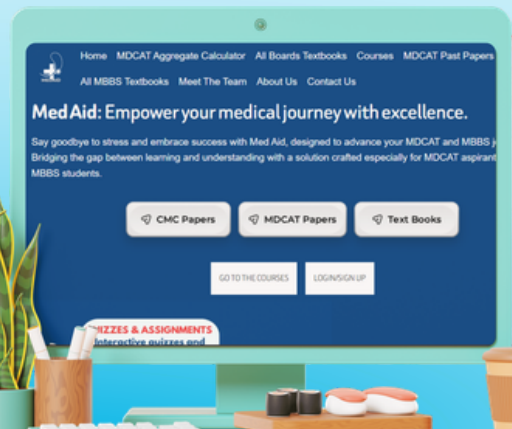
Review Your Mistakes

Bonus Talks:

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- **CMC MBBS** Past Papers With Explanations
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