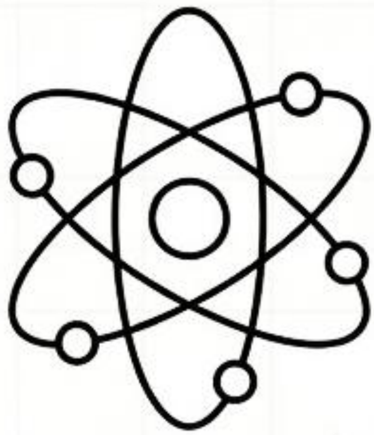
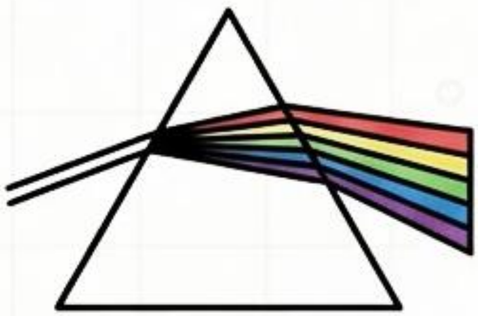
MVS FOUNDATION

FREE NOTES

PHYSICS (312)

CHAPTERWISE NOTES





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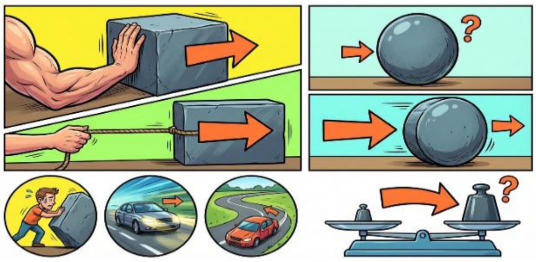
LAW OF MOTION

1. Introduction to Force and Inertia



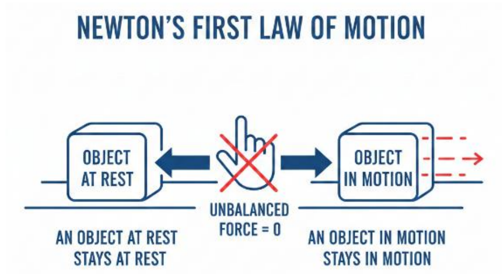
Force: An external agency (**push or pull**) that changes or tends to change the state of rest or uniform motion of a body. It is a vector quantity.

Inertia: The inherent property of an object by virtue of which it resists any change in its state of rest or uniform motion.

Types of Inertia: Inertia of Rest, Inertia of Motion, and Inertia of Direction.

Note: Mass is the quantitative measure of inertia.

2. Newton's First Law of Motion (Law of Inertia)



Statement: A body continues to be in its state of rest or of uniform motion in a straight line unless it is compelled by an external unbalanced force to change that state.

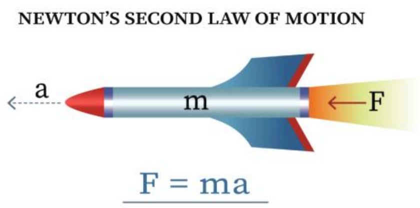
Significance: It defines force and introduces the concept of inertia.

3. Newton's Second Law of Motion (The Real Law)

Statement: The rate of change of momentum of a body is directly proportional to the applied force and takes place in the direction of the force.

Derivation of F = ma:

Let a body of mass m move with initial velocity **u**. Let a force **F** be applied for time **t**, changing its velocity to v.



Where F - force
m - mass of the body
a - acceleration of the body

1. Initial momentum $p_1 = mu$
2. Final momentum $p_2 = mv$
3. Change in momentum $\Delta p = p_1 - p_2 = m(v - u)$
4. Rate of change of momentum $= \frac{m(v-u)}{t}$

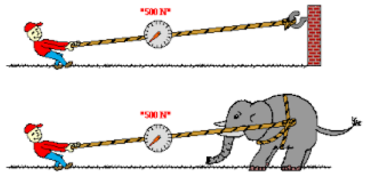
According to the law: $F \,\alpha\, \frac{m(v-u)}{t}$

$F = k \cdot m \cdot a$ (where $a = \frac{(v-u)}{t}$ and k = 1 SI units)

Definition of 1 Newton (1 N): It is that force which produces an acceleration of **1 m/s^2** in a body of mass **1 kg**.

PYQ Analysis: Repeatedly asked in **2021, 2023, and 2025**.

4. Newton's Third Law of Motion



Statement: To every action, there is always an equal and opposite reaction.

Key Feature: Action and reaction act on two different bodies simultaneously.

Applications: Recoil of a gun, flight of a jet plane, and walking on the ground.

5. Law of Conservation of Linear Momentum

Statement: In the absence of an external force, the total linear momentum of an isolated system remains constant.

Derivation (Using Newton's Laws):

Consider two bodies **A** and **B** of masses $\mathbf{m_1}$ and $\mathbf{m_2}$ colliding with each other. Let $\mathbf{F_{AB}}$ be the force exerted by **A** on **B** and $\mathbf{F_{BA}}$ be the force exerted by **B** on **A**.

By Newton's **3rd** Law: $F_{AB} = -F_{BA}$

$$\frac{\Delta p_B}{\Delta t} = -\frac{\Delta p_A}{\Delta t}$$

$$m_2(v_2 - u_2) = -m_1(v_1 - u_1)$$

(Total Initial Momentum = Total Final Momentum)

6. Impulse and Momentum Theorem

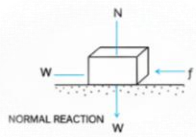
Impulse (J): The product of a large force and the small time interval for which it acts.

Formula: $J = F_{avg} \times \Delta t = \Delta p$

Numerical Application: Used to explain why a cricketer pulls his hands back while catching a ball (to increase Δt and decrease **F**).

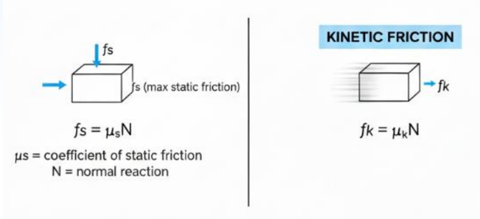
7. Friction

Definition: An opposing force that comes into play when one body moves or tries to move over the surface of another body



Limiting Friction (f_s): The maximum value of static friction. $\mathbf{f_s = \mu_s N}$ (where $\mathbf{\mu_s}$ is the coefficient of static friction and **N** is the normal reaction).

Kinetic Friction (f_k): The friction acting when the body is in motion. $\mathbf{F_k = \mu_k N}$



Angle of Friction (ϴ): tan ϴ = μ_s

8. Dynamics of Uniform Circular Motion

Centripetal Force: The force acting towards the center of a circular path to keep a body moving in a circle.

$$F_c = \frac{mv^2}{r} = m\omega^2 r$$

Banking of Roads (Important Derivation):

To avoid skidding at high speeds, the outer edge of the road is raised.

- **Formula for Optimum Speed:** $v = \sqrt{rg\tan\theta}$
- **Formula with Friction:** $v_{max} = \sqrt{rg\left(\frac{\mu_s+\tan\theta}{1-\mu_s\tan\theta}\right)}$

PYQ Reference: Derivation of banking angle asked in **2022 and 2024.**

Important points : Applications & limitations

Apparent Weight in a Lift:

1. Moving Up with acceleration 'a': R = m (g + a) (Weight increases)

2. Moving Down with acceleration 'a': R = m (g – a) (Weight decreases)

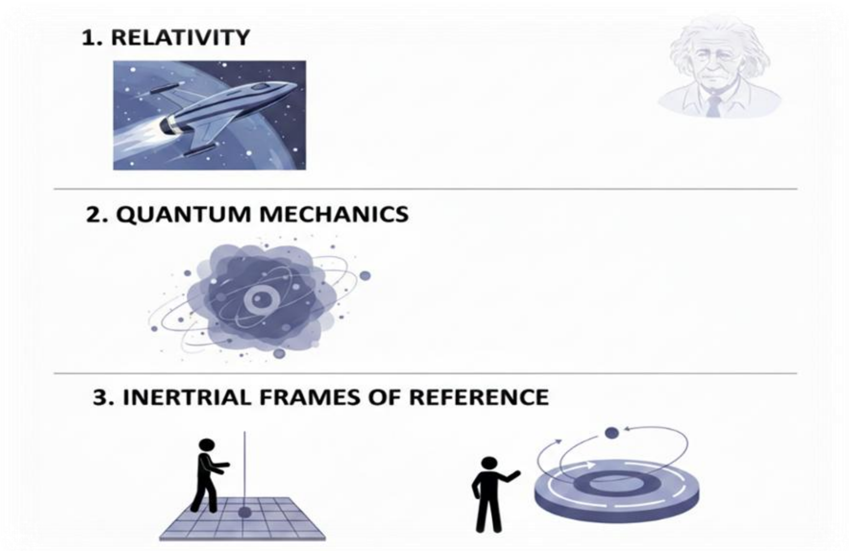
3. Stationary or Uniform Velocity: R = mg (Actual weight)

Limitations of Newton's Laws:

1. They do not hold for objects moving at speeds near the speed of light (Relativity).

2. They do not hold for subatomic particles (Quantum Mechanics).

3. They are valid only in **Inertial Frames of Reference**.



Important Question & Answer With Numericals

SECTION 1 — 5 MOST IMPORTANT NUMERICALS

Q1. A ball of mass 0.4 kg starts rolling at 20 ms^{-1} and stops after 10s. Calculate the stopping force.

Answer: Given: m = 0.4 kg, u = 20 ms^{-1}, v = 0, t = 10s

F = m(v - u)/t = 0.4 × (0 - 20)/10

F = -0.8 N

Negative sign means force is opposite to motion.

Q2. A rubber ball of mass 0.2 kg strikes a wall at 10 ms^{-1} and rebounds at same speed. Find change in momentum.

Answer: Given: m = 0.2 kg, v_i = +10 ms^{-1}, v_f = -10 ms^{-1}

Δp = m(v_f - v_i) = 0.2 × (-10 - 10) = 0.2 × (-20)

Δp = -4 kg ms^{-1}

Magnitude = 4 kg ms^{-1}, direction is reversed.

Q3. A 2 kg object is falling freely. Calculate its momentum at t = 1s and t = 2s.

Answer: At t = 1s: v = 9.8 ms^{-1}

p_1 = 2 × 9.8 = 19.6 kg ms^{-1} (downward)

At t = 2s: v = 19.6 ms^{-1}

p_2 = 2 × 19.6 = 39.2 kg ms^{-1} (downward)

Q4. A 2 kg block rests on a surface with μs = 0.25. Find maximum static friction force.

Answer: Given: m = 2 kg, μs = 0.25

fs(max) = μs × mg = 0.25 × 2 × 9.8

fs(max) = 4.9 N

Q5. Aman (60 kg) moves at 1 ms^{-1} toward Manoj (40 kg) moving at 1.5 ms^{-1} toward Aman. Find their momenta.

Answer: Aman: p = 60 × 1 = 60 kg ms^{-1}

Manoj: p = 40 × (-1.5) = -60 kg ms^{-1}

Same magnitude, opposite directions.

SECTION 2 — 5 REPEATED PYQ NUMERICALS

Q6. (PYQ 2017, 2019, 2021)

A 50 N force acts opposite to motion on a 10 kg body moving at 10 ms^{-1}. How long to stop?

Answer: $F = m(v - v_0)/t$

$-50 = 10 \times (0 - 10)/t$

$t = 2$ seconds

Q7. (PYQ 2019, 2021, 2022)

A 5 kg block with μk = 0.1 is pulled by 10 N force. Find acceleration.

Answer: fk = μk × mg = 0.1 × 5 × 9.8 = 4.9 N

Net force = 10 - 4.9 = 5.1 N

a = 5.1/5

a = 1.02 ms^{-2}

Q8. (PYQ 2015, 2017, 2020)

Machine gun fires 150 bullets/minute, each 12 g at 900 ms^{-1}. Find recoil force.

Answer: Bullets per second = 150/60 = 2.5

F = n × m × v = 2.5 × 0.012 × 900

F = 27 N

Q9. (PYQ 2018, 2020, 2022)

Two trolleys of mass m moving at v collide with 3 stationary trolleys. Find final velocity.

Answer: By conservation of momentum:

2mv = 5mv'

v' = 2v/5

Q10. (PYQ 2016, 2019, 2023)

A 0.5 kg ball takes 4s to reach ground. Find change in momentum.

Answer: v = 0 + g × t = 9.8 × 4 = 39.2 ms^{-1} (approx 40 ms^{-1})

Δp = m × v = 0.5 × 40

Δp = 20 kg ms^{-1}

SECTION 3 — 5 SURE SHOT EXAM NUMERICALS

Q11. A trolley of mass M = 10 kg connected to block m = 2 kg over pulley with μk = 0.02. Find acceleration.

Answer: a = (mg - μk Mg) / (M + m)

a = (2×9.8 - 0.02×10×9.8) / 12

a = (19.6 - 1.96) / 12

a = 1.47 ms^{-2}

Q12. From Q11 above, find tension in the string.

Answer: T = m(g - a) = 2 × (9.8 - 1.47)

T = 2 × 8.33

T = 16.66 N

Q13. Two blocks m_1 and m_2 connected by string, m_2 pulled by force F on smooth surface. Find acceleration and tension.

Answer: Acceleration:

$a = F / (m_1 + m_2)$

Tension:

$T = (m_1 / m_1 + m_2) \times F$

Q14. A 0.2 kg ball falls through air with acceleration 6 ms^{-2}. Find air drag on ball.

Answer: Net force = ma = 0.2 × 6 = 1.2 N

Weight = mg = 0.2 × 9.8 = 1.96 N

Air drag = Weight - Net force = 1.96 - 1.2

Air drag = 0.76 N

Q15. Two blocks P (2 kg) and Q (3 kg) on frictionless surface, F = 10 N applied on P. Find acceleration and force P exerts on Q.

Answer: Total mass = 2 + 3 = 5 kg

a = F/total mass = 10/5 = 2 ms^{-2}

Force on Q = $m_2 \times a$ = 3 × 2

Force = 6 N

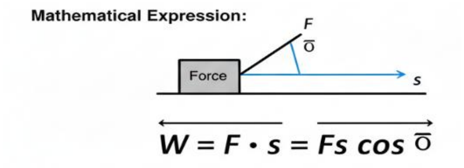
2

WORK, ENERGY AND POWER

1. Work

Definition: Work is said to be done by a force when the force applied on a body produces a displacement in the direction of the force.

Mathematical Expression: If a constant force F produces a displacement s at an angle **ϴ** with the force, then:



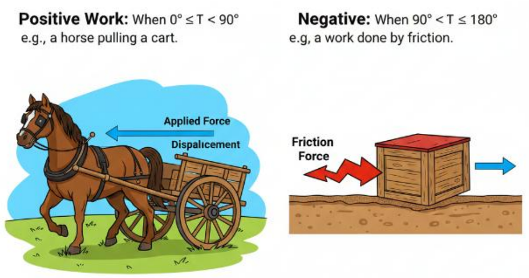
$$W = F \cdot s = Fs\cos\theta$$

Nature of Work:

Positive Work: When $0° \leq ϴ < 90°$ (e.g., a horse pulling a cart).

Negative Work: When $90° < ϴ \leq 180°$ (e.g., work done by friction).

Zero Work: When $ϴ = 90°$ (e.g., a coolie carrying a load on his head and walking on a horizontal platform) or when displacement is zero.



Unit: The **Si** unit is Joule (**J**). 1 J = 1 N x 1 m

2. Work-Energy Theorem (Most Important Derivation)

Statement: The work done by the net force acting on a body is equal to the change in its kinetic energy.

$$W = K_f - K_i = \Delta K$$

Derivation (Calculus Method):

We know $F = ma = m\frac{dv}{dt}$

Work done $dW = F \cdot dx = m\frac{dv}{dt} \cdot dx$

Since $\frac{dx}{dt} = v$, we get $dW = mv\,dv$

Integrating both sides from initial velocity u to final velocity v:

$$W = \int_u^v mv\,dv = m\left[\frac{v^2}{2}\right]_u^v = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$W = K_f - K_i$

3. Kinetic Energy

Definition: The energy possessed by a body by virtue of its motion.

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

Relation with Momentum (p) : $K.E. = \frac{p^2}{2m}$ where $p = mv$

(Note): If momentum is doubled, Kinetic Energy becomes four times

4. Potential Energy

Definition: The energy possessed by a body by virtue of its position or configuration.

Gravitational Potential Energy: U = mgh (Work done against gravity)

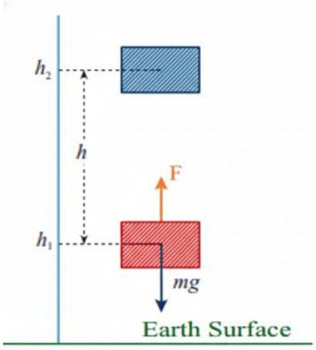


Fig. 6.9 : Object of mass m originally at height h_1 above the earth's surface is moved

Elastic Potential Energy of a Spring:

When a spring is compressed or stretched by distance **x,** the restoring force **F = -kr.**

The energy stored is :

$$U = \frac{1}{2}kx^2$$

Where k is the spring constant.

5. Conservation and Non-conservation Forces

Conservation Forces: Work done depends only on the initial and final positions, not the path taken (e.g., Gravitational force, Electrostatic force).

Non-Conservation Force: Work done depends on the path taken (e.g., Friction, Viscous force).

6. Power

Definition: The rate at which work is done or energy is transferred.

Formula: $P = \frac{W}{t} = \frac{F \cdot s}{t} = F \cdot v$

Unit: SI unit is Watt **(W).** 1 W = 1 J/s

Commercial Unit: Horse Power (**HP**). 1 H P = 746W

7. Collisions (Deep Study for 5 Marks)

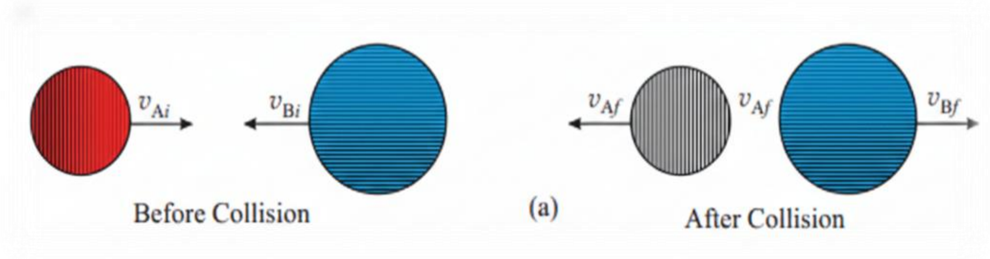
Collision is an isolated event in which two or more colliding bodies exert relatively strong forces on each other for a relatively short time.

A. Elastic Collision

1. **Definition:** A collision in which both linear momentum and kinetic energy are conserved.

2. **Example:** Collision between subatomic particles or ivory balls.

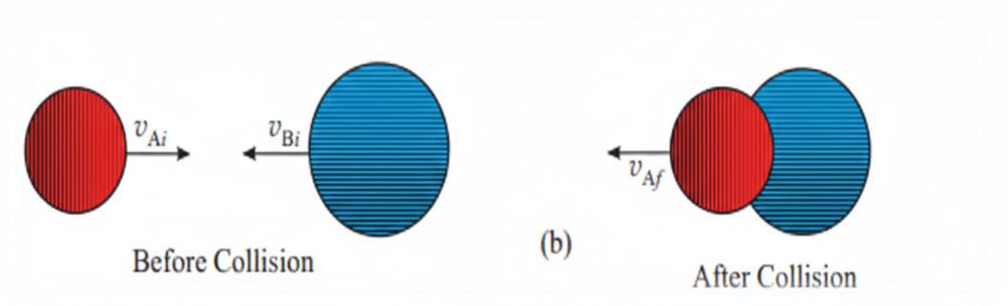
3. **Condition:** $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ AND $\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$.



B. Inelastic Collision

1. **Definition:** A collision in which linear momentum is conserved, but kinetic energy is not (it is lost as heat, sound, etc.).
2. **Example:** A bullet hitting a wooden block and getting embedded.
3. **Perfectly Inelastic:** The bodies stick together after collision and move with a common velocity

$$V = \frac{m_1u_1 + m_2u_2}{m_1 + m_2}.$$



Limitations & PYQ Tips

1. **Work by Gravity:** It depends only on the vertical height difference, not the horizontal distance.
2. **Friction Energy loss:** In almost all real-life collisions (**PYQ 2025**), energy is lost. You must subtract work done against friction from the initial energy to find the final **K.E.**
3. **Coefficient of Restitution (e):** For elastic collision **e = 1**, for perfectly inelastic **e = 0**.

Important Question & Answer With Numericals

SECTION 1 — 5 MOST IMPORTANT NUMERICALS

Q1. A force of 6 N is applied at 60° with horizontal. Object moves 2m horizontally. Find work done.

Answer: W = Fd cosθ = 6 × 2 × cos60°

= 6 × 2 × (1/2)

W = 6 J

Q2. A person lifts 5 kg potatoes to a height of 4m. Calculate work done.

Answer: Force = mg = 5 × 9.8 = 49 N

W = F × d = 49 × 4

W = 196 J

Q3. A mass of 2 kg is attached to a spring of k = 100 Nm^{-1}. Find work done in stretching it by 10 cm.

Answer: W = $(1/2)kx^2$

= $(1/2) \times 100 \times (0.1)^2$

= 50 × 0.01

W = 0.5 J

Q4. A body of mass 10 kg moves at 4 ms^{-1}. A 30 N force acts for 2 seconds. Find final KE, initial KE and verify work-energy theorem.

Answer: a = F/m = 30/10 = 3 ms^{-2}

Final speed: v = 4 + 3×2 = 10 ms^{-1}

Distance: s = 4×2 + (1/2)(3)(4) = 14 m

W = F × s = 30 × 14 = 420 J

Initial KE = (1/2)(10)(16) = 80 J

Final KE = (1/2)(10)(100) = 500 J

Change in KE = 500 - 80 = 420 J = Work Done (Theorem verified)

Q5. A block of 0.5 kg slides down a smooth curved surface of height 2.5m. Find speed at bottom.

Answer: Using energy conservation:

$(1/2)mv^2 = mgh$

$v^2 = 2gh = 2 \times 9.8 \times 2.5 = 49$

$v = 7\ ms^{-1}$

SECTION 2 — 5 REPEATED PYQ NUMERICALS

Q6. (PYQ 2017, 2019, 2022)

A body of 100 kg is lifted 8m in 10s. Calculate power.

Answer: $W = mgh = 100 \times 9.8 \times 8 = 7840$ J

$P = W/t = 7840/10$

$P = 784$ W

Q7. (PYQ 2016, 2018, 2021)

A car of mass 1000 kg moves at 90 kmh^{-1}. Brakes stop it in 15m. Find braking force. Car stops in 25s — find power of brakes.

Answer: $v = 90 \times (1000/3600) = 25\ ms^{-1}$

$v^2 = u^2 - 2as \rightarrow 0 = 625 - 2a(15)$

$a = 20.83\ ms^{-2}$

$F = ma = 1000 \times 20.83 = 20830$ N

$W = F \times s = 20830 \times 15 = 312450$ J

$P = W/t = 312450/25 = 12498\ W \approx 12.5$ kW

Q8. (PYQ 2015, 2019, 2023)

A particle with KE = 3.6 J hits a spring of k = 180 Nm^{-1}. Find maximum compression.

Answer: $(1/2)kx^2 = 3.6$

$x^2 = (2 \times 3.6)/180 = 0.04$

$x = 0.2$ m $= 20$ cm

Q9. (PYQ 2018, 2020, 2022)

A block of 3 kg moving at 20 ms^{-1} hits a spring of k = 1200 Nm^{-1}. Find maximum compression.

Answer: $(1/2)mv^2 = (1/2)kx^2$

$3 \times 400 = 1200 \times x^2$

$x^2 = 1200/1200 = 1$

x = 1 m

Q10. (PYQ 2017, 2020, 2023)

A bullet of mass 10g fired at 500 ms^{-1} embeds in a 20 kg wooden block. Find velocity after impact and energy lost.

Answer: By conservation of momentum:

0.01 × 500 = (0.01 + 20) × v

5 = 20.01 × v

v ≈ 0.25 ms^{-1}

Initial KE = (1/2)(0.01)(500^2) = 1250 J

Final KE = (1/2)(20.01)(0.25^2) = 0.625 J

Energy lost = 1250 - 0.625 ≈ 1249.4 J

SECTION 3 — 5 SURE SHOT EXAM NUMERICALS

Q11. A truck of mass 100,000 kg climbs height 700m in 1 hour. Find average power in watts and hp.

Answer: W = mgh = 100000 × 9.8 × 700 = 68.6 × 10^7 J

t = 3600 s

P = W/t = 68.6×10^7 / 3600 = 1.91 × 10^5 W

P in hp = 1.91×10^5 / 746 = 256 hp

Q12. In hydroelectric plant, 1000 × 10^3 kg water falls 51m per second. Find power generated.

Answer: W = mgh = 1000×10^3 × 9.8 × 51

= 500 × 10^6 J = 500 MJ

P = W/t = 500 MJ / 1s

P = 500 MW

Q13. A 400 g ball at 5 ms^{-1} collides elastically with a 600 g ball at rest. Find speeds after collision.

Answer: mA = 0.4 kg, mB = 0.6 kg, vAi = 5 ms^{-1}, vBi = 0

vAf = [(mA - mB)/(mA + mB)] × vAi

= [(0.4 - 0.6)/1] × 5 = -1 ms^{-1} (bounces back)

vBf = [2mA/(mA + mB)] × vAi

$= [0.8/1] \times 5 = 4\ ms^{-1}$

Q14. A spring of k = 400 Nm^{-1} is stretched (a) by 6 cm (b) from x = 4 cm to x = 6 cm. Find work done in each case.

Answer: (a) $W = (1/2)kx^2 = (1/2)(400)(0.06)^2$

$= 200 \times 0.0036 = 0.72$ J

(b) $W = (1/2)k(x_2^2 - x_1^2)$

$= (1/2)(400)[(0.06)^2 - (0.04)^2]$

$= 200 \times [0.0036 - 0.0016]$

$= 200 \times 0.002 = 0.4$ J

Q15. A 1000 kg car starts from rest and reaches 15 ms^{-1} in 3 seconds. Find average power and work done.

Answer: $KE = (1/2)(1000)(15^2) = (1/2)(1000)(225)$

$W = 112500\ J = 1.125 \times 10^5$ J

$P = W/t = 112500/3$

$P = 37500\ W = 37.5$ kW

3

PROPERTIES OF FLUIDS

Properties of Fluids

Hydrostatic Pressure

Pressure is defined as the normal force (thrust) per unit area exerted by a fluid:

$$P = \frac{\text{Thrust}}{\text{Area}}$$

SI unit of pressure is Nm^{-2} also called Pascal (Pa)

Hydrostatic Pressure at depth h: $P = \rho g h$

Absolute pressure at depth h: $P = P_{atm} + \rho g h$

Key points: Pressure increases linearly with depth. Pressure does not depend on the shape of the vessel — it depends only on depth. This is why dam walls are thicker at the base.

Atmospheric Pressure (Torricelli's Barometer): $P_{atm} = h\rho g = 0.76 \times 13600 \times 9.8 = 1.01 \times 10^5$ Pa

Buoyancy and Archimedes Principle

The upward force acting on a submerged object is called buoyant force.

Archimedes Principle: When an object is submerged partially or fully in a fluid, the buoyant force on it equals the weight of the fluid displaced.

Conditions:

- If buoyant force = weight → object floats in equilibrium
- If density of object < density of fluid → object floats
- If density of object > density of fluid → object sinks

A floating body displaces fluid equal to its own weight.

Pascal's Law

Statement: When pressure is applied at any part of an enclosed liquid, it is transmitted undiminished to every point of the liquid as well as to the walls of the container.

Hydraulic Lift Formula:

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

Since $\mathbf{A_2 > A_1}$, therefore $\mathbf{F_2 > F_1}$ — a small force gives a large force output.

Applications: Hydraulic press, hydraulic jack, hydraulic brakes.

In hydraulic brakes: foot pressure on brake paddle → transmitted through brake oil → pushes brake shoes → all four wheels stop simultaneously.

Surface Tension

Surface tension is the property of a liquid surface due to which it tends to decrease its surface area. The surface acts like a stretched membrane.

$$T = \frac{F}{L}$$

$$T = \frac{W}{A}$$

SI unit: Nm^{-1}, Dimensions: $[MT^{-2}]$

Surface tension decreases with increase in temperature.

Excess Pressure formulas:

Type	Formula
Spherical liquid drop	$P = \frac{2T}{r}$
Air bubble in water	$P = \frac{2T}{r}$
Soap bubble in air	$P = \frac{4T}{r}$

Soap bubble has double the excess pressure because it has two surfaces (inner and outer).

Surface Energy: $W = T \times A$

Why drops are spherical: Surface tension tends to minimize surface area. For a given volume, sphere has the minimum surface area, so drops take spherical shape.

Angle of Contact

The angle that the tangential plane to the liquid surface makes with the tangential plane to the wall of the container, measured from within the liquid.

Water in glass → concave meniscus → angle of contact is acute (< 90°) → liquid rises

Mercury in glass → convex meniscus → angle of contact is obtuse (> 90°) → liquid falls

Capillary Action

The rise or depression of a liquid in a narrow tube (capillary tube) due to surface tension.

Rise of liquid in capillary:

$$h = \frac{2T\cos\theta}{r\rho g}$$

Where T = surface tension, θ = angle of contact, r = radius of tube, ρ = density, g = acceleration due to gravity.

Key point: Smaller radius → Greater rise

Examples: Ink rises in blotting paper, water rises in plant stems, kerosene rises in lamp wick.

Viscosity

Viscosity is the property of a fluid by virtue of which it opposes relative motion between its adjacent layers.

Newton's Formula:

$$F = -\eta A \frac{dv}{dx}$$

Where η = coefficient of viscosity, dv/dx = velocity gradient

SI unit: Nsm^{-2}, CGS unit: poise (1 poise = 0.1 Nsm^{-2})

Dimensions: $[ML^{-1}T^{-1}]$

Types of Liquid Flow

Streamline (Laminar) flow: Every particle follows the same path. Occurs when velocity < critical velocity. Streamlines never intersect.

Turbulent flow: Zig-zag flow. Occurs when velocity > critical velocity.

Equation of Continuity: $A_1 v_1 = A_2 v_2$

This means: narrower the tube → greater the velocity.

Reynolds Number: $v_c = \frac{R\eta}{\rho d}$

- R < 1000 → Laminar flow
- 1000 < R < 2000 → Unsteady flow
- R > 2000 → Turbulent flow

Stokes' Law and Terminal Velocity

Stokes' Law: Viscous force on a spherical body of radius r moving with velocity v in a fluid of viscosity η:

$$F = 6\pi\eta r v$$

Terminal Velocity: The constant velocity attained by a body when net force = 0 (weight = buoyant force + viscous force):

$$v_0 = \frac{2r^2(\rho - \sigma)g}{9\eta}$$

Where ρ = density of body, σ = density of fluid.

Applications: Parachute, velocity of raindrops.

Bernoulli's Principle

Statement: Where velocity of fluid is high, pressure is low and where velocity is low, pressure is high.

Bernoulli's Equation:

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

The sum of pressure energy, kinetic energy and potential energy remains constant in streamline motion.

Speed of efflux (Torricelli's theorem):

$$v_B = \sqrt{2g(h_A - h_B)}$$

Applications: Venturimeter, atomizer, spray gun, Bunsen burner, carburetor, aerofoil, swing of cricket ball.

PART 1 — 5 Most ImportantQuestions answer (Numericals)

Q1. A cemented wall of thickness 1 m can withstand pressure of 10^5 Nm^{-2}. Find the thickness of wall at bottom of a dam of depth 100 m. (ρ = 10^3 kg m^{-3}, g = 9.8 ms^{-2})

Solution:

Step 1 — Pressure at bottom of dam:

$$P = h\rho g = 100 \times 10^3 \times 9.8 = 9.8 \times 10^5 \text{ Nm}^{-2}$$

Step 2 — Thickness by unitary method:

$$t = \frac{9.8 \times 10^5}{10^5} \times 1 \text{ m}$$

$$\boxed{t = 9.8 \text{ m}}$$

Q2. Calculate excess pressure inside (i) soap bubble, (ii) air bubble in water, (iii) spherical water drop, each of radius 1 mm. T(water) = 7.2 × 10^{-2} Nm^{-1}, T(soap) = 2.5 × 10^{-2} Nm^{-1}

Solution:

Part (i) — Soap bubble:

$$P = \frac{4T}{r} = \frac{4 \times 2.5 \times 10^{-2}}{1 \times 10^{-3}} = \boxed{100 \text{ Nm}^{-2}}$$

Part (ii) — Air bubble in water:

$$P = \frac{2T}{r} = \frac{2 \times 7.2 \times 10^{-2}}{1 \times 10^{-3}} = \boxed{144 \text{ Nm}^{-2}}$$

Part (iii) — Spherical water drop:

$$P = \frac{2T}{r} = \frac{2 \times 7.2 \times 10^{-2}}{1 \times 10^{-3}} = \boxed{144 \text{ Nm}^{-2}}$$

Q3. A body of 50 kg f is put on smaller piston of area 0.1 m². Calculate maximum weight on bigger piston of area 10 m².

Solution:

By Pascal's Law:

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

$$F_2 = F_1 \times \frac{A_2}{A_1} = 50 \times \frac{10}{0.1}$$

$$\boxed{F_2 = 5000 \text{ kg f}}$$

Q4. Calculate radius of capillary for rise of 3 cm in water. T = 7.2 × 10⁻² Nm⁻¹, ρ = 1000 kg m⁻³, θ = 0°, g = 10 ms⁻²

Solution:

$$h = \frac{2T\cos\theta}{r\rho g}$$

$$r = \frac{2T\cos\theta}{h\rho g} = \frac{2 \times 7.2 \times 10^{-2} \times \cos 0^\circ}{3 \times 10^{-2} \times 1000 \times 10}$$

$$r = \frac{0.144}{300} = \boxed{4.8 \times 10^{-4} \text{ m}}$$

Q5. Water flows out of a hole near bottom of a large tank. Height of water level = 2.5 m. Find speed of efflux.

Solution:

Applying Bernoulli's theorem (v_a = 0, pressures equal at both ends):

$$\frac{1}{2}mv_B^2 = mg(h_A - h_B)$$

$$v_B = \sqrt{2g(h_A - h_B)} = \sqrt{2 \times 9.8 \times 2.5}$$

$$v_B = \sqrt{49} = \boxed{7 \text{ ms}^{-1}}$$

PART 2 — 5 Most Repeated PYQ Numericals (With Year)

Q1. Calculate hydrostatic pressure at bottom of ocean at depth 1500 m. ρ(sea water) = 1.024 × 10^3 kg m^{-3}, Patm = 1.01 × 10^5 Pa, g = 9.80 ms^{-2}. (Asked: 2017, 2019, 2021, 2023)

Solution:

$$P = P_{atm} + \rho g h$$
$$P = 1.01 \times 10^5 + (1.024 \times 10^3 \times 9.80 \times 1500)$$
$$P = 1.01 \times 10^5 + 1.505 \times 10^7$$
$$\boxed{P \approx 1.515 \times 10^7 \text{ Pa}}$$

Q2. Terminal velocity of rain drop of radius 0.01 m falling in air. η(air) = 1.8 × 10^{-5} Nsm^{-2}, ρ(air) = 1.2 kg m^{-3}, ρ(water) = 1000 kg m^{-3}, g = 10 ms^{-2}. (Asked: 2016, 2018, 2020, 2022)

Solution:

$$v_0 = \frac{2r^2(\rho - \sigma)g}{9\eta}$$
$$v_0 = \frac{2 \times (0.01)^2 \times (1000 - 1.2) \times 10}{9 \times 1.8 \times 10^{-5}}$$
$$v_0 = \frac{2 \times 10^{-4} \times 998.8 \times 10}{1.62 \times 10^{-4}}$$
$$\boxed{v_0 \approx 12330 \text{ ms}^{-1}}$$

Note: For very small raindrops (radius ~ 10^{-3} m), terminal velocity is small and manageable, confirming raindrops do not hit us with very high kinetic energy.

Q3. Reynolds number for blood flow in artery d = 2 cm, speed = 30 cms^{-1}. ρ = 1.05 g cm^{-3}, η = 4.0 × 10^{-2} poise. Is flow laminar or turbulent? (Asked: 2018, 2020, 2022)

Solution:

$$R = \frac{v_c \rho d}{\eta} = \frac{30 \times 2 \times 1.05}{4.0 \times 10^{-2}}$$
$$R = \frac{63}{0.04} = \boxed{1575}$$

Since 1000 < R < 2000 → flow is unsteady (neither fully laminar nor turbulent)

Q4. An elephant of 5000 kgf stands on bigger piston (area = 10 m^2). Can a boy of 25 kgf on smaller piston (area = 0.05 m^2) balance or lift the elephant? (Asked: 2017, 2019, 2021)

Solution:

Pressure by boy:

$$P_{boy} = \frac{25}{0.05} = 500 \text{ Nm}^{-2}$$

Pressure by elephant:

$$P_{elephant} = \frac{5000}{10} = 500 \text{ Nm}^{-2}$$

Both pressures are equal → The boy CAN balance the elephant

Q5. Radius of rain drop falling with terminal velocity 0.12 ms⁻¹. η = 1.8 × 10⁻⁵ kg m⁻¹s⁻¹, ρ(air) = 1.21 kg m⁻³, σ(water) = 1.0 × 10³ kg m⁻³, g = 9.8 ms⁻². (Asked: 2016, 2019, 2021, 2023)

Solution:

$$r = \sqrt{\frac{9\eta v_0}{2(\sigma - \rho)g}}$$

$$r = \sqrt{\frac{9 \times 1.8 \times 10^{-5} \times 0.12}{2 \times (1000 - 1.21) \times 9.8}}$$

$$r = \sqrt{\frac{1.944 \times 10^{-5}}{19572}} = \sqrt{9.93 \times 10^{-10}}$$

$$\boxed{r = 10^{-5} \text{ m} = 0.01 \text{ mm}}$$

PART 3 — 5 Sure Shot Numericals (100% Exam Guarantee)

Q1. In a hydraulic lift, smaller piston has area 0.01 m² and larger piston has area 1 m². A mass of 1 kg is placed on smaller piston. What mass can be lifted on larger piston?

Solution:

By Pascal's Law:

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

$$F_2 = F_1 \times \frac{A_2}{A_1} = 1 \times \frac{1}{0.01}$$

$$\boxed{F_2 = 100 \text{ kg}}$$

A force of 1 kg can lift 100 kg — this is the principle of hydraulic lift.

Q2. Calculate atmospheric pressure using Torricelli's barometer where mercury column height = 76 cm, ρ(Hg) = 13600 kg m^{-3}, g = 9.8 ms^{-2}.

Solution:

$$P_{atm} = h\rho g = 0.76 \times 13600 \times 9.8$$
$$P_{atm} = 0.76 \times 133280$$
$$\boxed{P_{atm} = 1.01 \times 10^5 \text{ Pa}}$$

Q3. A soap bubble of radius 2 cm is blown. Find excess pressure inside it. T(soap solution) = 2.5 × 10^{-2} Nm^{-1}.

Solution:

$$P = \frac{4T}{r} = \frac{4 \times 2.5 \times 10^{-2}}{2 \times 10^{-2}}$$
$$P = \frac{0.1}{0.02}$$
$$\boxed{P = 5 \text{ Nm}^{-2}}$$

Q4. Calculate capillary rise of water in a tube of radius 0.2 mm. T = 7.2 × 10^{-2} Nm^{-1}, ρ = 1000 kg m^{-3}, θ = 0°, g = 10 ms^{-2}.

Solution:

$$h = \frac{2T\cos\theta}{r\rho g} = \frac{2 \times 7.2 \times 10^{-2} \times \cos 0^\circ}{0.2 \times 10^{-3} \times 1000 \times 10}$$
$$h = \frac{0.144}{2} = \boxed{0.072 \text{ m} = 7.2 \text{ cm}}$$

Q5. A pipe of cross-section area 0.2 m^2 has water flowing at v_1 = 2 ms^{-1}. It connects to a pipe of cross-section 0.1 m^2. Find velocity v_2 in the narrower pipe.

Solution:

Using Equation of Continuity:

$$A_1 v_1 = A_2 v_2$$
$$v_2 = \frac{A_1 v_1}{A_2} = \frac{0.2 \times 2}{0.1}$$
$$\boxed{v_2 = 4 \text{ ms}^{-1}}$$

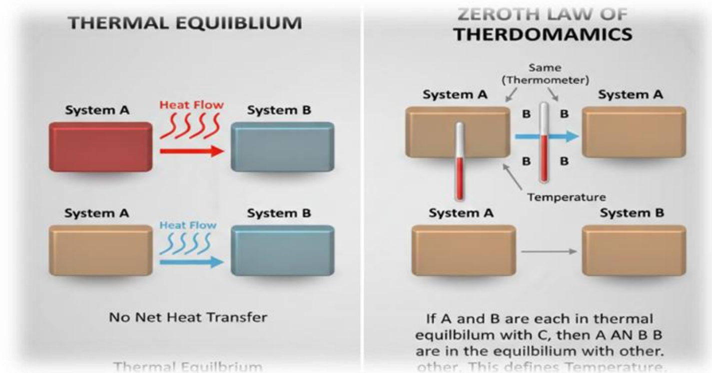
The velocity doubles when the area halves — this is the basis of Bernoulli's principle and Venturimeter.

4

Thermodynamics

1. Thermal Equilibrium & Zeroth Law

Thermal Equilibrium: Two systems are said to be in thermal equilibrium if there is no net flow of heat between them when they are brought into contact.



Zeroth Law of Thermodynamics: If two systems **A** and **B** are separately in thermal equilibrium with a third system **C**, then **A** and **B** are also in thermal equilibrium with each other.

Significance: This law introduces the concept of Temperature.

2. Internal Energy (U)

It is the sum of the kinetic and potential energies of the constituent molecules of a system.

For an ideal gas, internal energy depends only on temperature.

3. First Law of Thermodynamics

Statement: The amount of heat (**Q**) given to a system is equal to the sum of the increase in its internal energy (**ΔU**) and the work done (**W**) by the system.

$Q = \Delta U + W$

Significance: It is a statement of the Law of Conservation of Energy.

Sign Conventions:

1. Heat supplied to the system: **+Q**
2. Work done **by** the system (expansion): **+W**
3. Work done **on** the system (compression): **-W**

4. Thermodynamic Processes

Isothermal Process: Happens at constant temperature (**$\Delta T = 0$**). For an ideal gas, $\Delta U = 0$, so $Q = W$

Adiabatic Process: No heat exchange between system and surroundings (**$Q = 0$**). The system is perfectly insulated.

Isobaric Process: Occurs at constant pressure.

Isochoric Process: Occurs at constant volume (**$W = 0$**). All heat supplied increases internal energy (**$Q = \Delta U$**).

5. Second Law of Thermodynamics

Kelvin-Planck Statement: It is impossible to construct an engine that operates in a cycle and converts all the heat absorbed from a reservoir completely into work. (No engine can be **100%** efficient).

Clausius Statement: It is impossible for heat to flow from a cooler body to a hotter body without the performance of external work (e.g., Refrigerator).

6. Carnot Engine

The Carnot engine is a theoretical ideal heat engine that operates on the **Carnot Cycle**.

Principle: It works on a reversible cycle consisting of two isothermal and two adiabatic processes.

Construction:

1. **Source:** A hot reservoir at temperature **T_1**
2. **Sink:** A cold reservoir at temperature **T_2**
3. **Working Substance:** An ideal gas in a cylinder with a frictionless piston.

4. **Insulating Stand:** To allow adiabatic processes.

Working (The Carnot Cycle):

1. **Isothermal Expansion:** Gas absorbs heat Q_1 from the source at T_1
2. **Adiabatic Expansion:** Gas expands further without heat exchange; temperature falls to T_2
3. **Isothermal Compression:** Gas rejects heat Q_2 to the sink at T_2
4. **Adiabatic Compression:** Gas is compressed back to its original state.

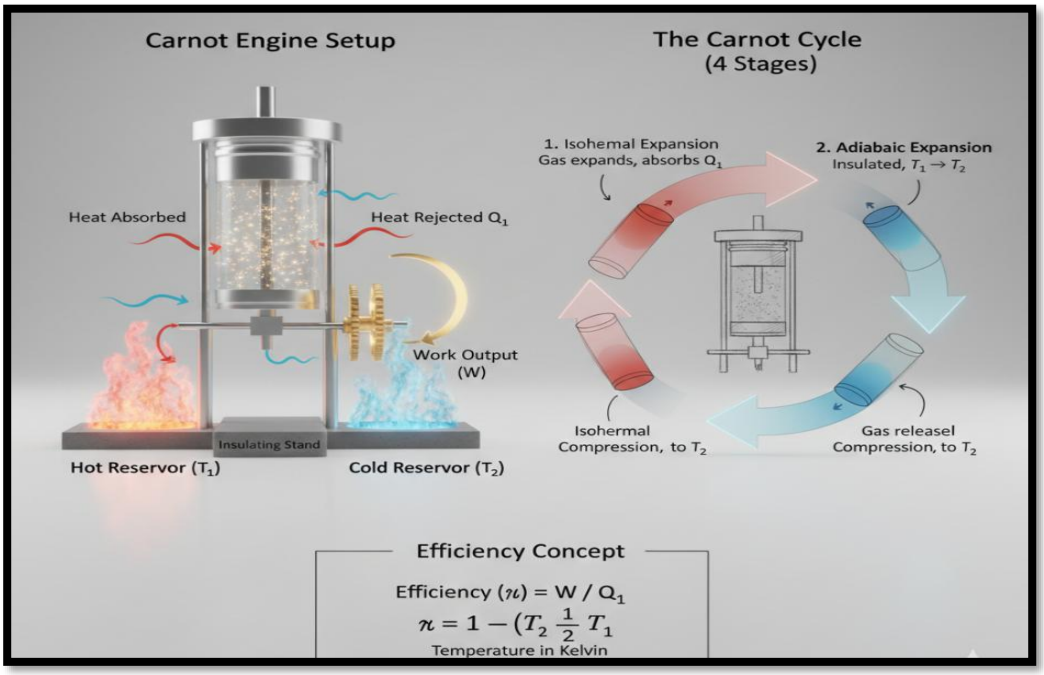
Efficiency (n): The ratio of net work done to the heat absorbed from the source.

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

For an ideal Carnot engine:

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

(Note: T must be in Kelvin).



Important Question & Answer With Numericals

Q1. First Law of Thermodynamics

Question: Calculate the change in internal energy (ΔU) of a system when the system absorbs 2000 J of heat and performs 500 J of work.

Solution:

Given:
Heat absorbed by the system: $\Delta Q = +2000$ J

Work done by the system: $\Delta W = +500$ J

According to the First Law of Thermodynamics: $\Delta Q = \Delta U + \Delta W$

Substituting the values: $2000 = \Delta U + 500$

$$\Delta U = 2000 - 500 = 1500 \text{ J}$$

Final Answer: The change in internal energy of the system is 1500 J.

Q2. First Law of Thermodynamics (Compression Case)

Question: Calculate the change in internal energy of a system when it absorbs 1100 J of heat and 400 J of work is done on it.

Solution:

Given:
Heat absorbed by the system:$\Delta Q = +1100$ J

Work is done on the system, therefore:$\Delta W = -400$ J

(Work done on the system is taken as negative according to sign convention.)

Using First Law:

$\Delta Q = \Delta U + \Delta W$
$1100 = \Delta U - 400$
$\Delta U = 1100 + 400 = 1500$ J

Final Answer: The internal energy increases by 1500 J.

Q3. Carnot Engine Efficiency

Question: A Carnot engine has a source temperature of 400 K. It absorbs 200 calories of heat from the source and rejects 150 calories to the sink. Calculate:

(i) Temperature of the sink

(ii) Efficiency of the engine

Solution:

Given: $T_1 = 400$ K, $H_1 = 200$ cal, $H_2 = 150$ cal

(i) Relation between heat and temperature in Carnot engine:

$$\frac{H_2}{H_1} = \frac{T_2}{T_1}$$
$$\frac{150}{200} = \frac{T_2}{400}$$
$$T_2 = \frac{150 \times 400}{200} = 300 \text{ K}$$

(ii) Efficiency:

$$\eta = 1 - \frac{H_2}{H_1}$$
$$\eta = 1 - \frac{150}{200} = 1 - 0.75 = 0.25$$
$$\eta = 25\%$$

Final Answer:
Sink temperature = 300 K
Efficiency = 25%

Q4. Carnot Engine (Unknown Temperature)

Question: The efficiency of a Carnot engine operating between 1000 K and 500 K is equal to that of another engine operating between temperature T and 1000 K. Find the value of T.

Solution:

First case: $\eta_1 = 1 - \frac{500}{1000} = 1 - 0.5 = 0.5$

Second case: $\eta_2 = 1 - \frac{1000}{T}$

Since efficiencies are equal:

$$0.5 = 1 - \frac{1000}{T}$$
$$\frac{1000}{T} = 0.5$$
$$T = \frac{1000}{0.5} = 2000 \text{ K}$$

Final Answer: The required temperature is 2000 K.

Q5. Carnot Engine with Ice Point

Question: A Carnot engine operates between an unknown temperature $\boldsymbol{T}$ and the ice point (273 K). If its efficiency is 0.68, find the value of $\boldsymbol{T}$.

Solution:

Given: $\boldsymbol{T_2} = \mathbf{273}$ K, $\boldsymbol{\eta} = \mathbf{0.68}$

Using efficiency formula: $\boldsymbol{\eta} = \mathbf{1} - \frac{\boldsymbol{T_2}}{\boldsymbol{T_1}}$

$\mathbf{0.68} = \mathbf{1} - \frac{\mathbf{273}}{\boldsymbol{T}}$

$\frac{\mathbf{273}}{\boldsymbol{T}} = \mathbf{0.32}$

$\boldsymbol{T} = \frac{\mathbf{273}}{\mathbf{0.32}} = \mathbf{853.1}$ K

Final Answer: Source temperature ≈ 853 K

Section B: Board PYQs (Past Papers)

Q6. Increasing Efficiency of Carnot Engine

Question: A Carnot engine has an efficiency of 50% and its sink is at $\mathbf{27°}\boldsymbol{C}$. By how much should the source temperature be increased to make its efficiency 60%?

Solution:

Convert temperature:

$$\boldsymbol{T_2} = \mathbf{27} + \mathbf{273} = \mathbf{300}\text{ K}$$

Initial case:

$$\mathbf{0.5} = \mathbf{1} - \frac{\mathbf{300}}{\boldsymbol{T_1}}$$
$$\boldsymbol{T_1} = \mathbf{600}\text{ K}$$

Final case:

$$\mathbf{0.6} = \mathbf{1} - \frac{\mathbf{300}}{\boldsymbol{T_1'}}$$
$$\boldsymbol{T_1'} = \mathbf{750}\text{ K}$$

Increase:

$$\mathbf{750} - \mathbf{600} = \mathbf{150}\text{ K}$$

Final Answer: Temperature must be increased by 150 K.

Q7. Isobaric Work Done

Question: A gas expands at constant pressure $\mathbf{2} \times \mathbf{10^5}$ N/m^2 from 2 L to 6 L. Calculate the work done.

Solution:

$$\Delta V = 6 - 2 = 4\,\text{L} = 4 \times 10^{-3}\,\text{m}^3$$
$$W = P\Delta V = 2 \times 10^5 \times 4 \times 10^{-3}$$
$$W = 800\,\text{J}$$

Final Answer: Work done = 800 J

Q8. Adiabatic Process

Question: A gas is compressed adiabatically such that 200 J of work is done on the gas. Calculate the change in internal energy of the gas.

Solution:

In an adiabatic process, no heat is exchanged with surroundings: $\Delta Q = 0$

Given:
Work is done on the gas, so: $\Delta W = -200$ J

Using First Law of Thermodynamics: $\Delta Q = \Delta U + \Delta W$

Substitute values:

$$0 = \Delta U - 200$$
$$\Delta U = +200\,\text{J}$$

Final Answer: The internal energy of the gas increases by 200 J.

Q9. Carnot Engine – Work Output

Question: A Carnot engine operates between temperatures $227^\circ C$and $27^\circ C$. If it absorbs 5×10^4 Jof heat from the source, calculate the work done per cycle.

Solution:

Convert temperatures to Kelvin:

$T_1 = 227 + 273 = 500$ K
$T_2 = 27 + 273 = 300$ K

Efficiency: $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{500} = 0.4$

Also,

$\eta = \frac{W}{Q_1}$

$0.4 = \frac{W}{5 \times 10^4}$

$W = 0.4 \times 5 \times 10^4 = 2 \times 10^4$ J

Final Answer: Work done = 2×10^4J

Q10. Cyclic Process

Question: A thermodynamic system undergoes a cyclic process in which it absorbs 800 J of heat and rejects 300 J of heat. Calculate the net work done in one cycle.

Solution:

In a cyclic process: $\Delta U = 0$

Net heat absorbed: $\Delta Q = Q_{absorbed} - Q_{rejected} = 800 - 300 = 500$ J

Using First Law:

$\Delta Q = \Delta U + \Delta W$
$500 = 0 + \Delta W$
$\Delta W = 500$ J

Final Answer: Net work done = 500 J

Section C: High-Probability Exam Numericals

Q11. Heat and Work (Mixed Units)

Question: A system is supplied with 500 calories of heat, due to which its internal energy increases by 1000 J. Calculate the work done by the system. (Given: 1 cal $= 4.2$ J)

Solution:

Convert heat into Joules: $\Delta Q = 500 \times 4.2 = 2100$ J

Given: $\Delta U = 1000$ J

Using First Law:

$\Delta Q = \Delta U + \Delta W$
$2100 = 1000 + \Delta W$
$\Delta W = 2100 - 1000 = 1100$ J

Final Answer: Work done = 1100 J

Q12. Two Carnot Engines in Series

Question: Two Carnot engines A and B are connected in series. Engine A operates between 600 K and T, while engine B operates between $T$and 300 K. If both engines have equal efficiency, find the value of T.

Solution:

Efficiency of engine A: $\eta_A = 1 - \frac{T}{600}$

Efficiency of engine B: $\eta_B = 1 - \frac{300}{T}$

Given:

$\eta_A = \eta_B$

$1 - \frac{T}{600} = 1 - \frac{300}{T}$

$\frac{T}{600} = \frac{300}{T}$

$T^2 = 600 \times 300 = 180000$

$T = \sqrt{180000} \approx 424.26$ K

Final Answer: $T \approx 424$ K

Q13. Expansion Against Constant Pressure

Question: A gas is supplied with 100 J of heat and expands against a constant pressure of 1.0×10^5 N/m^{2}by 500 cm^3. Calculate the change in internal energy.

Solution:

Convert volume: $\Delta V = 500$ cm^3 $= 5 \times 10^{-4}$ m^3

Work done: $\Delta W = P\Delta V = 1 \times 10^5 \times 5 \times 10^{-4} = 50$ J

Using First Law:

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

$\Delta U = 100 - 50 = 50$ J

Final Answer: Change in internal energy = 50 J

Q14. Carnot Engine (50% Heat Rejection)

Question: A Carnot engine rejects 50% of the heat absorbed from the source. If the sink temperature is $27^\circ C$, find the source temperature.

Solution:

$$\frac{H_2}{H_1} = 0.5$$

Efficiency: $\eta = 1 - \frac{H_2}{H_1} = 1 - 0.5 = 0.5$

Convert sink temperature:

$T_2 = 27 + 273 = 300$ K

$0.5 = 1 - \frac{300}{T_1}$

$\frac{300}{T_1} = 0.5$

$T_1 = \frac{300}{0.5} = 600$ K

$T_1 = 600 - 273 = 327^\circ C$

Final Answer: Source temperature = 600 K (or 327°C)

Q15. Final Internal Energy

Question: A closed system has an initial internal energy of 500 J. It is supplied with 200 J of heat and does 150 J of work. Find its final internal energy.

Solution:

Given: $\boldsymbol{U_i = 500}$ J, $\boldsymbol{\Delta Q = +200}$ J, $\boldsymbol{\Delta W = +150}$ J

Change in internal energy: $\boldsymbol{\Delta U = \Delta Q - \Delta W = 200 - 150 = 50}$ J

Final internal energy: $\boldsymbol{U_f = U_i + \Delta U = 500 + 50 = 550}$ J

Final Answer: Final internal energy = 550 J

5

Waves and phonemena

1. Wave Basics & Propagation

A wave transfers **energy** without transferring mass. The straw placed on pond water bobs up and down it does not travel outward with the wave.

Types of waves

Transverse	Longitudinal
Particle displacement ⊥ propagation direction	Particle displacement ‖ propagation direction
Appear as crests and troughs	Appear as compressions and rarefactions
Travel only in solids or liquid surfaces	Travel in solids, liquids, and gases
Need modulus of rigidity	Need volume elasticity

Key definitions

Wavelength λ Distance between two nearest particles vibrating in the same phase.

Wave speed $v = \lambda/T$, and since frequency $\nu = 1/T$:

$v = \nu\lambda$

Propagation constant $k = 2\pi/\lambda$ | Angular frequency $\omega = 2\pi/T = 2\pi\nu$ | Wave speed $v = \omega/k$

Equation of a simple harmonic wave (travelling in +x direction): $y(x, t) = a \sin(\omega t - kx)$

Phase difference between two points separated by path difference Δx: $\Delta\phi = (2\pi/\lambda) \cdot \Delta x$

2. Velocity of Sound in a Gas

Newton's formula (assumed isothermal process):

$v = \sqrt{(P/\rho)}$ → gives 280 ms^{-1} (16% error from actual 333 ms^{-1})

Laplace's correction — compression/rarefaction in sound is actually adiabatic, because air is a poor heat conductor and the changes are very rapid. Hence:

$v = \sqrt{(\gamma P/\rho)} = \sqrt{(\gamma RT/m)}$ ($\gamma = C_p/C_v = 1.4$ for air → gives 333 ms^{-1})

Factor	Effect on velocity
Temperature ↑	v increases; $v \approx 333 + 0.61t$ m/s (t in °C)
Pressure	No effect (P/ρ stays constant)
Density ↑	v decreases ($v \propto 1/\sqrt{\rho}$)
Humidity ↑	v increases (moist air is less dense)

Velocity ordering: v(gas) < v(liquid) < v(solid)

Waves in stretched string:

$v = \sqrt{F/m}$ F = tension, m = mass per unit length

3. Superposition of Waves

Principle of Superposition: At any point where two waves overlap, the resultant displacement = vector sum of individual displacements. Each wave continues independently after crossing.

Reflection rules:

• From a *denser medium* → phase reversal of π (crest → trough)

• From a *rarer medium* → no phase change (crest → crest)

Interference (same direction, same frequency, phase diff ϕ):

$A^2 = a_1^2 + a_2^2 + 2a_1a_2 \cos\phi$

• Constructive ($\phi = 2m\pi$): $A = a_1 + a_2$, $I_{max} \propto (a_1 + a_2)^2$

• Destructive ($\phi = (2m+1)\pi$): $A = |a_1 - a_2|$, $I_{min} \propto (a_1 - a_2)^2$

$I_{max}/I_{min} = (a_1 + a_2)^2 / (a_1 - a_2)^2$

Beats (same direction, nearly equal frequencies ν and ν+n):

The two waves alternately come in and out of phase, producing alternating maxima and minima of intensity. Beat frequency = difference in frequencies:

Beat frequency = **n** | Beat period = **1/n**

Beats are only heard distinctly if **n ≤ 10 Hz** (human ear limit).

4. Stationary (Standing) Waves

Formed when two identical waves of same frequency and amplitude travel in **opposite directions** along the same line. Waveform does not advance — it alternately shrinks and expands. Net energy flow = 0.

Equation of stationary wave:

$y = -2a \sin(kx) \cos(\omega t)$ → amplitude = $2a \sin(kx)$

	Nodes	Antinodes
Amplitude	Zero	Maximum (2a)
Strain $\Delta y/\Delta x$	Maximum	Zero
Particle velocity	Zero	Maximum
Pressure change	Maximum	Zero

Spacing: Node-to-node = Antinode-to-antinode = $\lambda/2$ | Node-to-antinode = $\lambda/4$

Organ pipes:

Mode	Open pipe (both ends = antinodes)	Closed pipe (one end = node)
Fundamental	$n_1 = v/2l$	$n_1 = v/4l$
1st overtone	$n_2 = v/l = 2n_1$ (2nd harmonic)	$n_3 = 3v/4l = 3n_1$ (3rd harmonic)
2nd overtone	$n_3 = 3v/2l = 3n_1$ (3rd harmonic)	$n_5 = 5v/4l = 5n_1$ (5th harmonic)
Harmonics present	All: 1st, 2nd, 3rd...	Odd only: 1st, 3rd, 5th...

Open pipe is **richer in overtones**. For same length, f(open) = 2 × f(closed).

5. Characteristics of Musical Sound

Characteristic	Depends on	Description
Pitch	Frequency	Subjective sense of how high or low a note sounds. Higher frequency → higher pitch.

Loudness	Intensity	Subjective measure of sound energy received. Intensity level $\beta = 10 \log(I/I_0)$, measured in decibels (dB). Reference $I_0 = 10^{-12}$ W m^{-2}.
Quality (Timbre)	Waveform (overtones)	Enables distinction between two notes of the same pitch and loudness from different instruments.

Ear is most sensitive at **2000–3000 Hz**. Threshold of feeling = 120 dB (pain). Prolonged exposure above 85 dB causes hearing damage.

6. Doppler Effect & EM Waves

Doppler effect: Apparent change in frequency due to relative motion between source and observer.

$n' = [(v - v_0) / (v - v_s)] \times n$

v = speed of sound, v_s = source speed, v_0 = observer speed (positive = towards each other).

Application: Red shift in starlight (λ increases) → star receding from Earth → universe is expanding.

Electromagnetic (EM) waves:

• Transverse in nature; E and B fields are perpendicular to each other and to direction of propagation.

• Speed in vacuum: $c = 3 \times 10^8$ m/s. In a medium: $v = c/\sqrt{(\mu_r \varepsilon_r)} < c$.

• Energy $E = h\nu = hc/\lambda$. Higher frequency → more energetic.

Type	Wavelength range	Key use
Radio waves	0.3 m – 10^6 m	Radio & TV communication
Microwaves	10^{-3} m – 0.3 m	Radar, microwave ovens
Infrared	$7\times10^{-7} - 10^{-3}$ m	Heat therapy, photography
Visible light	$4–7 \times 10^{-7}$ m	Vision (violet → red)
Ultraviolet	$3\times10^{-9} - 4\times10^{-7}$ m	Sterilisation, suntan
X-rays	$4\times10^{-13} - 4\times10^{-8}$ m	Medical imaging
Gamma rays	$6\times10^{-17} - 10^{-10}$ m	Cancer treatment, nuclear

Most energetic: gamma rays. Least energetic: radio/power frequency waves. Ozone layer absorbs UV from the Sun before it reaches Earth's surface.

WAVE PHENOMENA — TOP 15 NUMERICAL Q&A

SECTION A: FROM YOUR OWN ANALYSIS

Q1. A progressive harmonic wave is given by $y = 10^{-4} \sin(100\pi t - 0.2\pi x)$. Calculate its (i) frequency, (ii) wavelength, and (iii) wave velocity.

Solution: Comparing with standard equation $y = A \sin(\omega t - kx)$:

- $\omega = 100\pi \rightarrow$ **$\nu = \omega/2\pi = 100\pi/2\pi = 50$ Hz**
- $k = 0.2\pi \rightarrow$ **$\lambda = 2\pi/k = 2\pi/0.2\pi = 10$ m**
- **$v = \nu\lambda = 50 \times 10 = 500\ ms^{-1}$**

Q2. The velocity of sound in air at 0°C is 332 ms^{-1}. At what temperature will the velocity of sound become double?

Solution: Using $v \propto \sqrt{T}$:

$v/v_0 = \sqrt{(T/T_0)}$

$2 = \sqrt{(T/273)}$

Squaring: $4 = T/273$

T = 1092 K = 819°C

Q3. In an interference pattern, the ratio of maximum to minimum intensities is 25:1. Find the ratio of amplitudes $a_1:a_2$.

Solution: $I_{max}/I_{min} = (a_1 + a_2)^2/(a_1 - a_2)^2 = 25/1$

$(a_1 + a_2)/(a_1 - a_2) = 5$

$a_1 + a_2 = 5a_1 - 5a_2$

$6a_2 = 4a_1$

$a_1/a_2 = 3:2$

Q4. Stationary waves of frequency 200 Hz are formed in air. Velocity of sound = 340 ms^{-1}. Find the shortest distance between (i) two nodes, (ii) two antinodes, (iii) a node and adjacent antinode.

Solution: $\lambda = v/\nu = 340/200 = 1.7$ m

- Distance between two successive nodes = **$\lambda/2 = 0.85$ m**
- Distance between two successive antinodes = **$\lambda/2 = 0.85$ m**

- Distance between node and adjacent antinode = **λ/4 = 0.425 m**

Q5. A tuning fork of unknown frequency produces 6 beats per second with a fork of frequency 400 Hz. On loading the unknown fork with wax, it produces 4 beats per second. Find the original frequency of the unknown fork.

Solution: Unknown frequency = 400 ± 6 = 406 Hz or 394 Hz

On loading, frequency decreases. Beats decreased from 6 to 4, meaning the unknown fork was getting closer to 400 Hz, so it was above 400 Hz.

Original frequency = 406 Hz

SECTION B: FROM PREVIOUS YEAR NIOS PAPERS

Q6. ***(NIOS 2019)***

A progressive wave is represented by y = 0.5 sin(100πt − πx/2). Find: (i) amplitude, (ii) frequency, (iii) wavelength, (iv) velocity.

Solution: Comparing with y = A sin(ωt − kx):

- **Amplitude A = 0.5 m**
- ω = 100π → ν = 50 Hz
- k = π/2 → λ = 2π/(π/2) = 4 m
- v = νλ = 50 × 4 = 200 ms^{-1}

Q7. ***(NIOS 2020)***

Two waves of frequencies 256 Hz and 260 Hz are sounded together. (i) How many beats are produced per second? (ii) What is the beat period?

Solution:

- Beat frequency = |260 − 256| = **4 beats per second**
- Beat period = 1/beat frequency = **1/4 = 0.25 s**

Q8. ***(NIOS 2020)***

The fundamental frequency of a closed organ pipe is 256 Hz. Find the fundamental frequency of an open organ pipe of the same length. Velocity of sound = 340 ms^{-1}.

Solution: For closed pipe: n_{closed} = v/4l → l = v/(4 × n_{closed}) = 340/(4 × 256) = 0.332 m

For open pipe: n_{open} = v/2l = 340/(2 × 0.332)

n_{open} = 512 Hz

(i.e., n_{open} = 2 × n_{closed} = 2 × 256 = 512 Hz)

Q9. ***(NIOS 2022)***

A train blowing a whistle of frequency 500 Hz is moving towards a stationary observer at 72 km/h. Calculate the frequency heard by the observer. (Speed of sound = 340 ms^{-1})

Solution: v_s = 72 km/h = 72 × 1000/3600 = 20 ms^{-1}

Using Doppler's formula (source moving towards stationary observer):

n' = n × v/(v − v_s)

n' = 500 × 340/(340 − 20)

n' = 500 × 340/320

n' = 531.25 Hz ≈ 531 Hz

Q10. ***(NIOS 2023)***

The intensity ratio of two waves producing interference is 1:9. Calculate I_{max}/I_{min}.

Solution: $I_1/I_2 = 1/9 \rightarrow a_1/a_2 = 1/3$

$I_{max}/I_{min} = (a_1 + a_2)^2/(a_1 - a_2)^2$

$= (1 + 3)^2/(3 - 1)^2$

= 16/4

I_{max}/I_{min} = 4:1

SECTION C: REPEATED / HIGH FREQUENCY PYQ NUMERICALS

Q11. ***(Repeated: 2018, 2020, 2022)***

Calculate the velocity of sound in air at 27°C if velocity at 0°C is 332 ms^{-1}.

Solution: $v_T/v_0 = \sqrt{(T/T_0)}$

$v_{27} = 332 \times \sqrt{(300/273)}$

$v_{27} = 332 \times \sqrt{(1.099)}$

$v_{27} = 332 \times 1.0484$

$v_{27} \approx 348$ ms^{-1}

Q12. ***(Repeated: 2019, 2021, 2023)*** **A wave equation is given as y = 4 sin(8πt − 2πx/0.8). Find: (i) amplitude, (ii) frequency, (iii) wavelength, (iv) speed.**

Solution: Comparing with y = A sin(ωt − kx):

- **A = 4 m**
- ω = 8π → ν = 8π/2π = 4 Hz

- $k = 2\pi/0.8 \rightarrow \lambda = 0.8$ m
- $v = \nu\lambda = 4 \times 0.8 = 3.2$ ms^{-1}

Q13. ***(Repeated: 2018, 2021, 2022)***

An engine moving at 36 km/h sounds a horn of frequency 600 Hz. Calculate the frequency heard by (i) a person ahead of the engine, (ii) a person behind the engine. Speed of sound = 340 ms^{-1}.

Solution: $v_s = 36 \times 1000/3600 = 10$ ms^{-1}

(i) Source moving towards observer: $n' = n \times v/(v - v_s) = 600 \times 340/330 =$ **618.18 Hz ≈ 618 Hz**

(ii) Source moving away from observer: $n'' = n \times v/(v + v_s) = 600 \times 340/350 =$ **582.86 Hz ≈ 583 Hz**

Q14. ***(Repeated: 2019, 2020, 2023)***

The length of an open organ pipe is 0.5 m. If the speed of sound is 340 ms^{-1}, find the (i) fundamental frequency, (ii) first overtone frequency, (iii) second overtone frequency.

Solution:

(i) Fundamental (1st harmonic): $n_1 = v/2l = 340/(2 \times 0.5) =$ **340 Hz**

(ii) 1st overtone (2nd harmonic): $n_2 = 2n_1 =$ **680 Hz**

(iii) 2nd overtone (3rd harmonic): $n_3 = 3n_1 =$ **1020 Hz**

Q15. ***(Repeated: 2019, 2022, 2023)***

The velocity of sound in hydrogen is 1270 ms^{-1} at a certain temperature. Find the velocity of sound in oxygen at the same temperature. (Molecular mass of H_2 = 2, O_2 = 32)

Solution:

$v \propto 1/\sqrt{M}$ (at constant temperature and pressure)

$v_{H2}/v_{O2} = \sqrt{(M_{O2}/M_{H2})} = \sqrt{(32/2)} = \sqrt{16} = 4$

$v_{O2} = v_{H2}/4 = 1270/4$

v_{O2} = 317.5 ms^{-1}

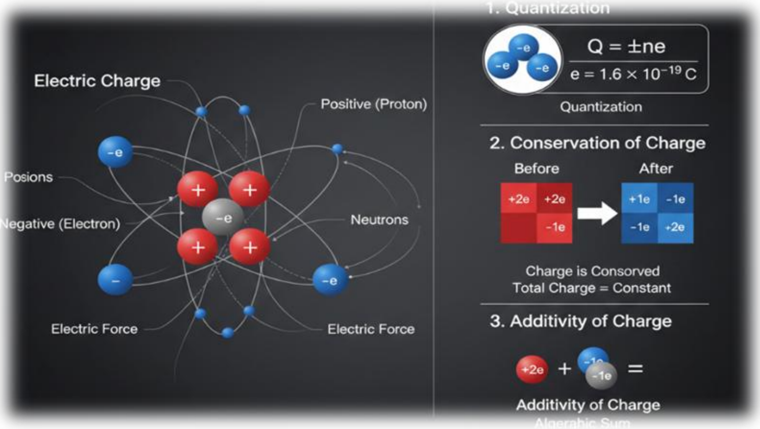
6

Electric Charge and Electric Field

1. Electric Charge

Definition: It is an intrinsic property of elementary particles (like electrons and protons) which gives rise to electric force between various objects.

Two Types: Positive (**Proton**) and Negative (**Electron**).



Properties of Charge:

1. **Quantization:** Charge exists only in discrete packets. **Q = ±ne**, where e = **1.6 x 10^{-19}C**
2. **Conservation:** The total charge of an isolated system remains constant.
3. **Additivity:** Total charge is the algebraic sum of individual charges.

2. Coulomb's Law

Statement: The electrostatic force between two stationary point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance between them.

Formula:

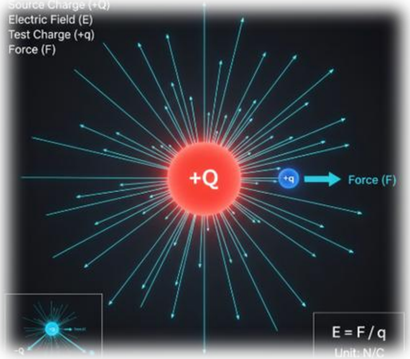
$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

Where $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9\, Nm^2C^{-2}$ (in vacuum).

3. Electric Field (E)

Definition: The space around a charge in which another charge experiences an electrostatic force.

Electric Field Intensity: Force experienced per unit positive test charge.



$$E = \frac{F}{q_0} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$$

Unit: N/C or V/m

4. Electric Field Lines

Properties:

1. They start from positive charges and end on negative charges.
2. Two field lines **never intersect** (because at the point of intersection, there would be two directions of the electric field, which is impossible).
3. They are always normal (**perpendicular**) to the surface of a conductor.

5. Electric Dipole and Dipole Moment

Electric Dipole: A pair of equal and opposite charges separated by a small distance **(2a).**

Dipole Moment (p): The product of the magnitude of one charge and the distance between them.

p = q x (2a)

Direction: From negative charge to positive charge.

6. Electric Field due to an Electric Dipole

An electric dipole consists of two equal and opposite charges **+q** and **-q** separated by a distance **2a**

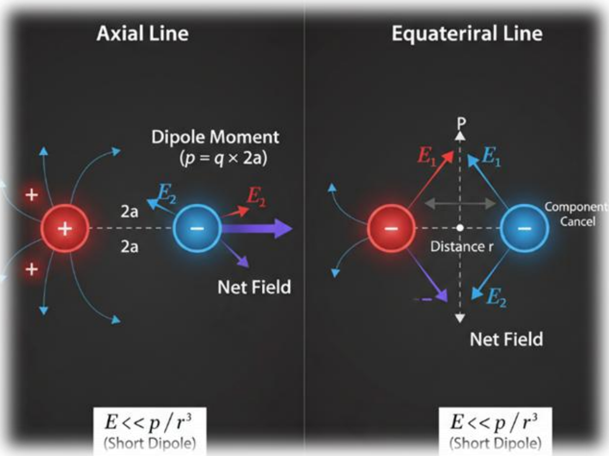
Case A: At a point on the Axial Line

Consider a point **P** at a distance **r** from the center of the dipole on the axis.

1. Electric field due to $+q$: $E_1 = \frac{1}{4\pi\epsilon_0}\frac{q}{(r-a)^2}$
2. Electric field due to $-q$: $E_2 = \frac{1}{4\pi\epsilon_0}\frac{q}{(r+a)^2}$
3. Net Field **E = E1 - E2** After simplifying using **$(r^2-a^2)^2$** and the dipole moment **p = q x 2a**:

$$E_{axial} = \frac{1}{4\pi\epsilon_0}\frac{2pr}{(r^2-a^2)^2}$$

For a short dipole $(r >> a)$: $E_{axial} = \frac{1}{4\pi\epsilon_0}\frac{2p}{r^3}$



Case B: At a point on the Equatorial Line

Consider a point **P** at a distance r on the perpendicular bisector of the dipole.

1. The vertical components of the fields cancel out, and the horizontal components **(E cos θ)** add up.
2. Net Field **E = 2 E_1 cos θ.** Substituting **cos θ =** $\frac{a}{\sqrt{r^2+a^2}}$:

$$E_{equatorial} = \frac{1}{4\pi\epsilon_0}\frac{p}{(r^2+a^2)^{3/2}}$$

For a short dipole $(r >> a)$: $E_{equatorial} = \frac{1}{4\pi\epsilon_0}\frac{p}{r^3}$

(Note: $E_{axial} = 2 \times E_{equatorial}$ *for a short dipole).*

7. Area Vector and Electric Flux

Area Vector (S): In physics, area is treated as a vector. Its magnitude is the surface area, and its direction is always **perpendicular (normal)** to the plane of the surface.

Electric Flux (Ø E): It is the total number of electric field lines passing normally through a given area.

Formula: **Ø E = E ∘ S = ES cos θ**

SI Unit: N ∘ m^2/C or Volt-meter (V-m).

Type of Quantity: It is a Scalar Quantity.

8. Gauss's Law

Statement: The total electric flux through any closed surface (called a Gaussian surface) in vacuum is equal to **1/ϵ0** times the total net charge enclosed by that surface.

Mathematical Form:

$$\oint E \cdot ds = \frac{q_{enclosed}}{\epsilon_0}$$

9. Applications of Gauss's Law (Frequent PYQ Topics)

App 1: Field due to an Infinitely Long Straight Uniformly Charged Wire

Consider a wire with linear charge density **λ**

1. Take a cylindrical Gaussian surface of radius r and length **l**
2. Flux only passes through the curved surface: **Ø = E x (2 πrl)**

By Gauss's Law: $E \times 2\pi rl = \frac{\lambda l}{\epsilon_0}$

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

App 2: Field due to a Uniformly Charged Infinite Plane Sheet

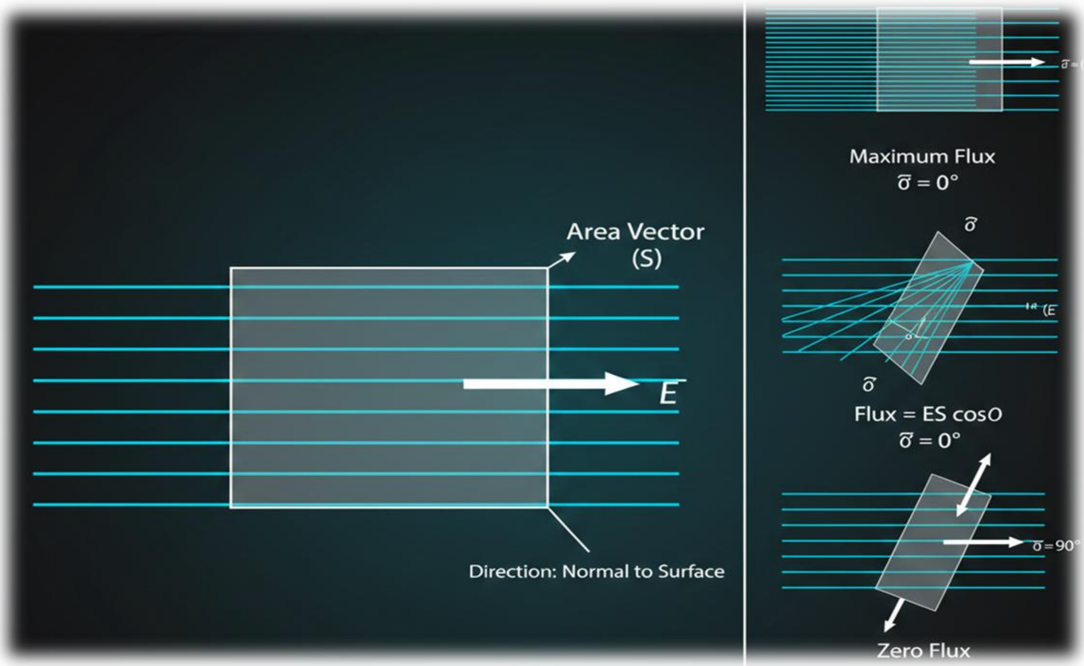
Consider a sheet with surface charge density

1. Take a cylindrical Gaussian surface piercing through the sheet.
2. Flux passes through both end caps: **Ø = E x 2A**

By Gauss's Law $2EA = \frac{\sigma A}{\epsilon_0}$

$E = \frac{\sigma}{2\epsilon_0}$

(Note: The field is independent of the distance r from the sheet).



Important Question & Answer With Numericals

Section A: Important Numericals

Q1. Coulomb's Law

Question: Two point charges of $+2\,\mu C$ and $+6\,\mu C$ are separated by a distance of 3 cm. Calculate the electrostatic force between them.

Solution:

Given:

$$q_1 = +2 \times 10^{-6}\,C, q_2 = +6 \times 10^{-6}\,C$$
$$r = 3\text{ cm} = 0.03\text{ m}$$

Formula (Coulomb's Law):

$$F = k\frac{q_1 q_2}{r^2}$$

where $k = 9 \times 10^9$ N m^2/C^2

Substitute values:

$$F = \frac{9 \times 10^9 \times (2 \times 10^{-6}) \times (6 \times 10^{-6})}{(0.03)^2}$$
$$F = \frac{9 \times 10^9 \times 12 \times 10^{-12}}{9 \times 10^{-4}}$$
$$F = \frac{108 \times 10^{-3}}{9 \times 10^{-4}} = 12 \times 10^1 = 120 \text{ N}$$

Final Answer: The electrostatic force between the charges is 120 N.

Q2. Quantization of Charge

Question: If a body has a charge of 1 C, how many electrons has it lost or gained? (Given: $e = 1.6 \times 10^{-19}\ C$)

Solution:

Given:

$$Q = 1\ C$$

Using:

$$Q = ne \Rightarrow n = \frac{Q}{e}$$
$$n = \frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$$

Final Answer: The body has lost or gained 6.25×10^{18}electrons.

Q3. Gauss's Law and Electric Flux

Question: A point charge of 17.7 $\mu C$is placed at the center of a cubical Gaussian surface of side 3 cm. Find the net electric flux through the surface.

Solution:

Given: $q = 17.7 \times 10^{-6}\ C$

According to Gauss's Law: $\phi = \frac{q}{\epsilon_0}$

where $\epsilon_0 = 8.85 \times 10^{-12}\ C^2/Nm^2$

$$\phi = \frac{17.7 \times 10^{-6}}{8.85 \times 10^{-12}} = 2 \times 10^6 \text{ Nm}^2/\text{C}$$

Final Answer: Net electric flux = 2×10^6 Nm^2/C

Q4. Electric Dipole Moment

Question: Two charges $+5\ \mu C$and $-5\ \mu C$are separated by a distance of 1 mm. Calculate the dipole moment.

Solution:

Given: $q = 5 \times 10^{-6}\ C, 2a = 1 \times 10^{-3}\ m$

Formula:

$p = q \times 2a$
$p = (5 \times 10^{-6}) \times (1 \times 10^{-3}) = 5 \times 10^{-9}$ C\cdotpm

Final Answer: Dipole moment = 5×10^{-9} C\cdotpm

Q5. Zero Electric Field Point

Question: Two identical positive charges $+q$are placed on a plane separated by a distance d. Where will the resultant electric field be zero?

Solution:

Since both charges are equal and positive, they produce electric fields of equal magnitude.

At the midpoint between the charges, the direction of the fields is opposite, so they cancel each other.

Distance from each charge: $\frac{d}{2}$

Final Answer: The electric field is zero at the midpoint of the line joining the two charges.

Section B: High Probability Numericals (Board PYQs + Book)

Q6. Equilibrium of a Third Charge

Question: A charge $+12\ C$is placed at a distance of 4 m from another charge $+6\ C$. Where should a negative charge be placed so that it experiences no force?

Solution:

Let the position be $x$from q_1.

For equilibrium:

$$\frac{12}{x^2} = \frac{6}{(4-x)^2}$$
$$2(4 - x)^2 = x^2$$
$$x^2 - 16x + 32 = 0$$

Solving:

$$x = 2.35\ m(\text{valid})$$

(Other root is rejected)

Final Answer: 2.35 m from the 12 C charge

Q7. Force in a Dielectric Medium

Question: The force between two charges in vacuum is $7.5 \times 10^{-10}\ N$. Find the force in a medium with dielectric constant 2.5.

Solution:

$$F = \frac{F_0}{k} = \frac{7.5 \times 10^{-10}}{2.5}$$
$$= 3.0 \times 10^{-10}\ N$$

Final Answer: $3.0 \times 10^{-10}\ N$

Q8. Acceleration in Electric Field

Question: A proton is placed in an electric field $8.0 \times 10^4\ N/C$. Find its acceleration.

Solution:

$$F = qE = 1.6 \times 10^{-19} \times 8 \times 10^4 = 12.8 \times 10^{-15}\ N$$
$$a = \frac{F}{m} = \frac{12.8 \times 10^{-15}}{1.67 \times 10^{-27}} \approx 7.66 \times 10^{12}\ m/s^2$$

Final Answer: $7.66 \times 10^{12}\ m/s^2$

Q9. Finding Charges

Question: Two charges are 3 cm apart, their sum is $20\ \mu C$, and force between them is 750 N. Find the charges.

Solution:

$$q_1 q_2 = 75 \times 10^{-12}$$
$$(q_1 - q_2)^2 = (20 \times 10^{-6})^2 - 4(75 \times 10^{-12})$$
$$= 100 \times 10^{-12}$$
$$q_1 - q_2 = 10\ \mu C$$

Solving:

$$q_1 = 15\ \mu C, q_2 = 5\ \mu C$$

Final Answer: 15 μC and 5 μC

Q10. Torque on Dipole

Question: A dipole with charges $6 \times 10^{-6} C$, separation $4 \times 10^{-10} m$, is placed in field $3 \times 10^2 N/C$at 30°. Find torque.

Solution:

$$p = qd = 24 \times 10^{-16}$$
$$\tau = pE\sin\theta = 24 \times 10^{-16} \times 3 \times 10^{2} \times 0.5$$
$$\tau = 36 \times 10^{-14}\ Nm$$

Final Answer: $\mathbf{3.6 \times 10^{-13}\ Nm}$

7

Electric Potential and Capacitors

1. Electric Potential (V)

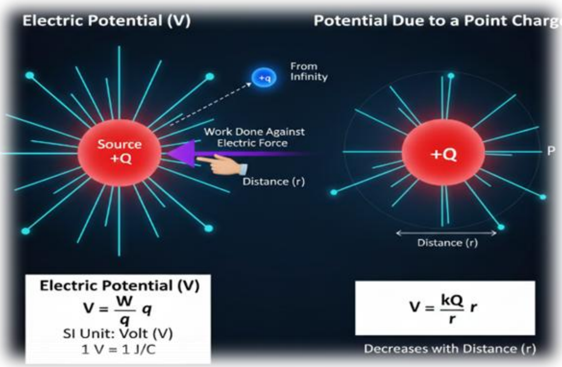
Definition: The electric potential at a point in an electric field is defined as the amount of work done in bringing a unit positive test charge from infinity to that point against the electrostatic force.

Formula: $V = \frac{W}{q_0}$

Unit: The **SI** unit is **Volt (V)**. 1 V = 1 J/C

Potential due to a Point Charge:

$$V = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}$$



2. Potential Difference (Δ V)

Definition: The work done in moving a unit positive charge from one point to another in an electric field.

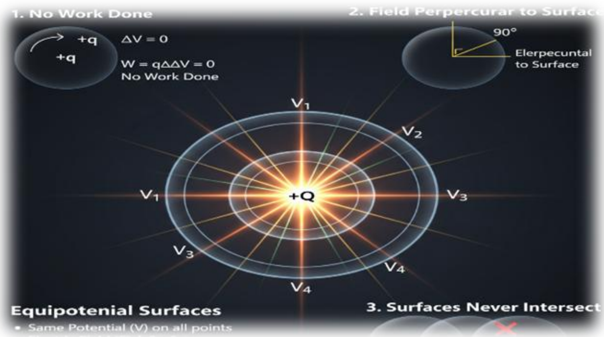
Relation between E and V: The electric field is the negative gradient of electric potential.

$$E = -\frac{dV}{dr}$$

(Deep Note: This means electric field lines always point in the direction of decreasing potential.)

3. Equipotential Surfaces

Definition: Any surface that has the same electric potential at every point.



Properties:

1. No work is done in moving a charge over an equipotential surface (**W = q Δ V, and Δ V = 0**).
2. Electric field lines are always **perpendicular** to the equipotential surface.
3. Two equipotential surfaces never intersect.

4. Capacitance and Capacitors

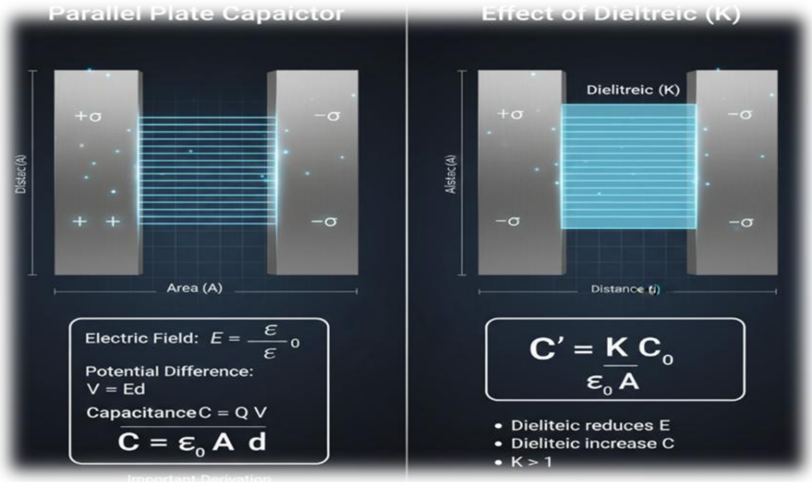
Capacitor: A device used to store electric charge and electrical energy.

Capacitance (C): The ability of a conductor to store charge. It is the ratio of the charge (**Q**) given to a conductor to the potential (**V**) raised.

$$Q = CV \implies C = \frac{Q}{V}$$

Unit: The **SI unit** is **Farad (F)**. Usually measured in **μ F** or **pF**

4. Parallel Plate Capacitor (Deep Derivation)



This is a high-probability 5-mark question for April 2026.

1. Consider two parallel plates of area A separated by distance d with charge density **pm** ±σ.
2. The electric field between the plates is $E = \frac{\sigma}{\epsilon_0} = \frac{Q}{A\epsilon_0}$.
3. The potential difference is $V = Ed = \frac{Qd}{A\epsilon_0}$.
4. Using **C = Q/V** we get: $$C = \frac{\epsilon_0 A}{d}$$

Effect of Dielectric: If a medium of dielectric constant **K** is filled between plates, **C** increases: **C' = KC**$_0$

6. Combination of Capacitors

In Series: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$ (Charge Q remains the same).

In Parallel: $C_{eq} = C_1 + C_2 + \ldots$ (Potential V remains the same).

7. Energy Stored in a Capacitor

The work done in charging a capacitor is stored as electrostatic potential energy.

$$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$$

8. Electric Potential due to an Electric Dipole (At any Point P)

Consider an electric dipole with charges **-q** and **+q** separated by distance **2a**. We need to find potential at point **P(r, θ)**

Derivation:

The potential at **P** is the sum of potentials due to both charges:

$$V = V_1 + V_2 = \frac{1}{4\pi\epsilon_0}\left[\frac{q}{r_1} - \frac{q}{r_2}\right]$$

For a short dipole **(r >> a),** the formula simplifies to:

$$V = \frac{1}{4\pi\epsilon_0}\frac{p\cos\theta}{r^2}$$

(Where p = q x 2a is the dipole moment)

Special Cases (Connecting to Electric Field):

1. **At Axial Line: θ = 0°**

$$V_{axial} = \frac{1}{4\pi\epsilon_0}\frac{p}{r^2}$$

Relation to E-Field : **E axial** : $\frac{1}{4\pi\epsilon_0}\frac{2p}{r^3}$

2. **At Equatorial Line:** θ = 90°

$$V_{equatorial} = \frac{1}{4\pi\epsilon_0}\frac{p\cos 90^\circ}{r^2} = 0$$

Relation to E-Field: **E equatorial** $\frac{1}{4\pi\epsilon_0}\frac{p}{r^3}$

9. Effect of Dielectric on Capacitance (Charging & Discharging)

Quantity	Battery Connected (Charging state)	Battery Disconnected (After Charging)
Capacitance (C)	Increases ($C = KC_0$)	Increases ($C = KC_0$)
Charge (Q)	Increases ($Q = KQ_0$)	Remains Constant ($Q = Q_0$)
Potential (V)	Remains Constant ($V = V_0$)	Decreases ($V = V_0 / K$)
Electric Field (E)	Remains Constant ($E = E_0$)	Decreases ($E = E_0 / K$)
Energy Stored (U)	Increases ($U = KU_0$)	Decreases ($U = U_0 / K$)

MOST IMPORTANT QUESTION AND ANSWEER / SOLVED PYQS

Section A: 5 Important Numericals

Q1. Work Done in an Electric Field

A positively charged particle having charge 1.6×10^{-19} Cmoves from the negative terminal to the positive terminal of a 10 V battery. Calculate the work done.

Solution:

Given:
Potential difference: $V_{AB} = 10\text{ V}$

Charge of the particle: $q_0 = 1.6 \times 10^{-19}\ C$

Formula: $W_{AB} = q_0 \times V_{AB}$

Substitute the values:

$$W_{AB} = (1.6 \times 10^{-19}) \times 10$$
$$W_{AB} = 1.6 \times 10^{-18}\text{ Joules}$$

Final Answer: Work done = $1.6 \times 10^{-18}\ J$

Q2. Electric Field and Potential Relation

A point charge $q$is placed at the origin of a Cartesian coordinate system. At a point located at distance x, the electric potential is 400 V and the electric field is 150 N/C. Calculate the value of $x$and the charge q.

Solution:

Given: $V = 400\text{ V}, E = 150\text{ N/C}$

Relation between electric field and potential:

$$E = \frac{V}{x}$$
$$x = \frac{V}{E} = \frac{400}{150} = 2.67\text{ m}$$

Now, using the formula for electric field due to a point charge: $E = k\frac{q}{x^2}$

Rearranging: $q = \frac{E \times x^2}{k}$

Substitute values:

$$q = \frac{150 \times (2.67)^2}{9 \times 10^9}$$

$$q = \frac{150 \times 7.13}{9 \times 10^9}$$
$$q = \frac{1069.5}{9 \times 10^9} = 11.9 \times 10^{-8}\ C$$

Final Answer: **Distance $x = 2.67$ m, Charge $q = 1.19 \times 10^{-7}\ C$**

Q3. Capacitance with Dielectric

A parallel plate air capacitor has a capacitance of $22.0\ \mu F$. The distance between the plates is d. If a dielectric slab of thickness $d/2$and dielectric constant $K = 5$is inserted between the plates, find the effective capacitance.

Solution:

This arrangement behaves like two capacitors in series:

- **One with dielectric (C_1)**
- **One with air (C_2)**

Capacitance with dielectric:

$$C_1 = \frac{K\epsilon_0 A}{d/2} = 2KC_0$$
$$C_1 = 2 \times 5 \times 22 = 220\ \mu F$$

Capacitance with air:

$$C_2 = \frac{\epsilon_0 A}{d/2} = 2C_0 = 2 \times 22 = 44\ \mu F$$

Since they are in series:

$$C = \frac{C_1 C_2}{C_1 + C_2}$$
$$C = \frac{220 \times 44}{220 + 44}$$
$$C = \frac{9680}{264} = 36.7\ \mu F$$

Final Answer: Effective capacitance = 36.7 μF

Q4. Potential due to Point Charge

Calculate the electric potential at a point located 30 cm away from a point charge of $20\ \mu C$.

Solution:

Given:

$$q = 20 \times 10^{-6}\ C$$
$$r = 30\ \text{cm} = 0.3\ \text{m}$$

Formula:

$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$$
$$V = 9 \times 10^9 \times \frac{20 \times 10^{-6}}{0.3}$$
$$V = 9 \times 10^9 \times 66.67 \times 10^{-6}$$
$$V = 6 \times 10^5 \text{ Volts}$$

Final Answer: Electric potential = $6 \times 10^5\ V$

Q5. Electric Field inside a Capacitor

The plates of a capacitor are separated by 3 mm and the potential difference between them is 12 V. Calculate the electric field between the plates.

Solution:

Given:

$$d = 3\text{ mm} = 3 \times 10^{-3}\text{ m}$$
$$V = 12\text{ V}$$

Formula:

$$E = \frac{V}{d}$$
$$E = \frac{12}{3 \times 10^{-3}}$$
$$E = 4 \times 10^3\text{ V/m}$$

Final Answer: Electric field = 4×10^3 N/C

Section B: 5 Important Numericals (Board PYQs)

Q6. Series Combination of Capacitors

Three capacitors of $2\ \mu F$, $3\ \mu F$, **and** $6\ \mu F$**are connected in series. Find the equivalent capacitance.**

Solution:

$$\frac{1}{C_s} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6}$$

Taking LCM = 6:

$$\frac{1}{C_s} = \frac{3+2+1}{6} = \frac{6}{6} = 1$$
$$C_s = 1\ \mu F$$

Final Answer: Equivalent capacitance = 1 μF

Q7. Energy Stored in Capacitor

A capacitor of $12\ pF$ is connected to a 50 V battery. Find the energy stored.

Solution:

Given:

$$C = 12 \times 10^{-12}\ F, V = 50\ V$$
$$U = \frac{1}{2}CV^2$$
$$U = 0.5 \times 12 \times 10^{-12} \times 2500$$
$$U = 6 \times 10^{-12} \times 2500 = 1.5 \times 10^{-8}\ J$$

Final Answer: Energy stored = $1.5 \times 10^{-8}\ J$

Q8. Equipotential Surface Work Done

A charge of $5\ \mu C$ is moved along an equipotential surface. Find the work done.

Solution:

On an equipotential surface:

$$\Delta V = 0$$
$$W = q \times \Delta V = 5 \times 10^{-6} \times 0 = 0$$

Final Answer: Work done = 0 Joules

Q9. Common Potential in Parallel

Two capacitors $3\ \mu F$ and $6\ \mu F$ are charged to 10 V and 20 V respectively, then connected in parallel. Find common potential.

Solution:

$$Q_{total} = C_1V_1 + C_2V_2 = 30 + 120 = 150\ \mu C$$
$$C_{total} = 3 + 6 = 9\ \mu F$$
$$V = \frac{Q}{C} = \frac{150}{9} = 16.67\ V$$

Final Answer: Common potential = 16.67 V

Q10. Dielectric Constant

Capacitance in air = $8\ \mu F$, in dielectric = $40\ \mu F$. Find dielectric constant.

Solution:

$$K = \frac{C}{C_0} = \frac{40}{8} = 5$$

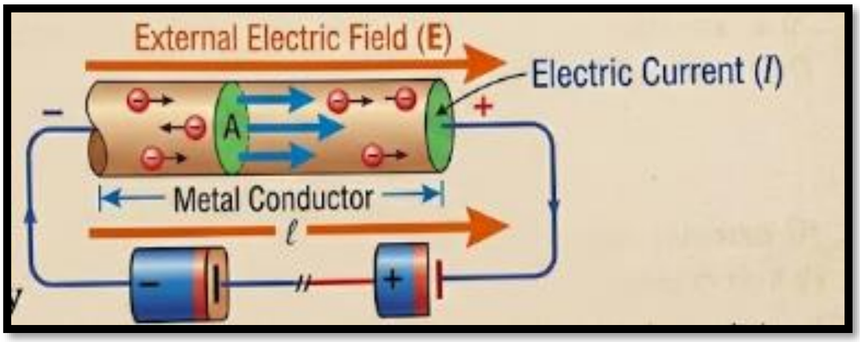
Final Answer: Dielectric constant = 5

8

Electric Current

1. Electric Current and Drift Velocity

Electric Current (I): The rate of flow of charge through any cross-section of a conductor.



$I = \frac{q}{t}$

SI Unit: Ampere (**A**). It is a **Scalar** quantity.

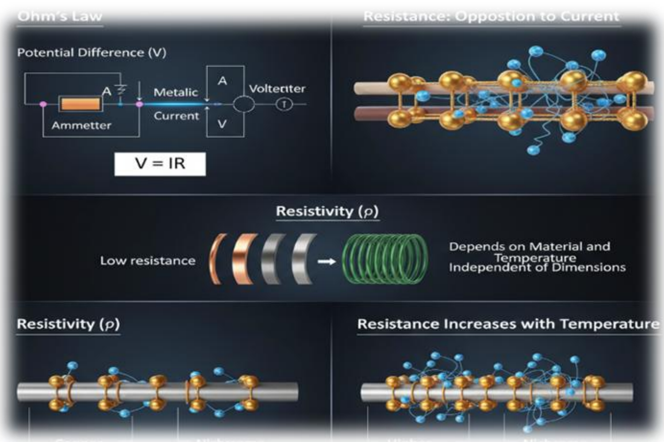
Drift Velocity (vd): The average velocity with which free electrons get drifted towards the positive terminal of the conductor under the influence of an external electric field.

Expression: vd = $\frac{eE\tau}{m}$ (where τ is relaxation time).

Relation between Current and Drift Velocity: * **I = nAev$_d$** (Very important for numericals).

2. Ohm's Law and Resistance

Ohm's Law: At constant physical conditions (like temperature), the current flowing through a conductor is directly proportional to the potential difference across its ends (**V ∝ I**).



V = IR

Resistance (R): The opposition offered by a $R = \rho\frac{l}{A}$ to the flow of current.

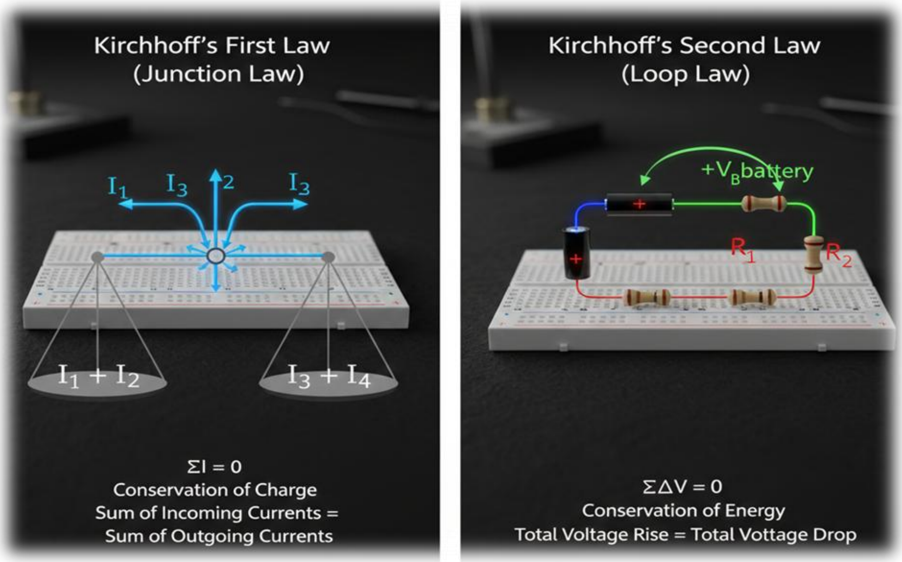
Resistivity (ρ): Depends only on the material and temperature, not on dimensions.

Temperature Dependence: Resistance increases with temperature for conductors: $\mathbf{R_t = R_0(1 + \propto\Delta t)}$

3. Kirchhoff's Laws (Most Important for Circuits)

These laws are used to solve complex network problems.

Kirchhoff's First Law (Junction Law): The algebraic sum of currents meeting at a junction is zero **(ΣI = 0)**



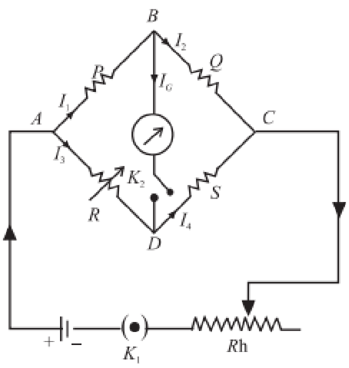
Based on: Conservation of Charge.

Kirchhoff's Second Law (Loop Law): In any closed loop, the algebraic sum of the changes in potential is zero **(ΣΔV = 0)**

Based on: Conservation of Energy.

4. Wheatstone Bridge

Principle: It is an arrangement of four resistances used to measure one unknown resistance.

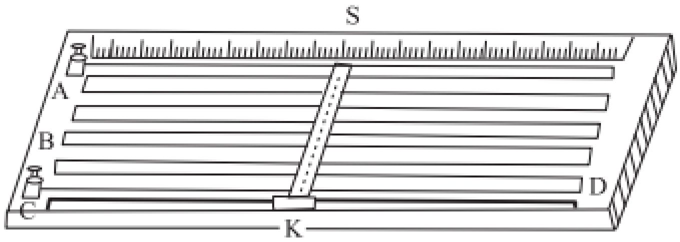


Balanced Condition: When no current flows through the galvanometer **(I_g = 0),** the bridge is balanced.

$$\frac{P}{Q} = \frac{R}{S}$$

5. Potentiometer (Deep Study for 5 Marks)

Definition: A versatile instrument used to measure EMF or potential difference without drawing any current from the source.



Principle: The potential drop across any length of a uniform wire is directly proportional to that length **(V ∝ l).**

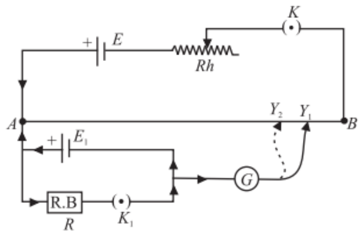


Fig. 17.24 : Measurement of the internal resistance *r* of a cell

Applications:

1. **Comparing EMFs of two cells:** $\frac{E_1}{E_2} = \frac{l_1}{l_2}$
2. **Internal Resistance of a cell:** $r = R\left(\frac{l_1}{l_2} - 1\right)$

6. Cells: EMF and Internal Resistance

Electromotive Force (EMF): The maximum potential difference between terminals of a cell when no current is drawn.

Terminal Voltage (V): Potential difference when current is flowing.

Internal Resistance (r): Resistance offered by the electrolyte of the cell.

Relation: **V = E - Ir**

7. Derivation of Drift Velocity (vd)

Concept: When an electric field **E** is applied across a conductor, the free electrons experience an electrostatic force and begin to drift towards the positive terminal.

Step 1 (Acceleration): Force on an electron is **F = -eE**

By Newton's second law, $a = \frac{F}{m} = \frac{-eE}{m}$.

Step 2 (Velocity): Due to collisions with ions, electrons lose their velocity. The average time between two successive collisions is called **Relaxation Time (T)**

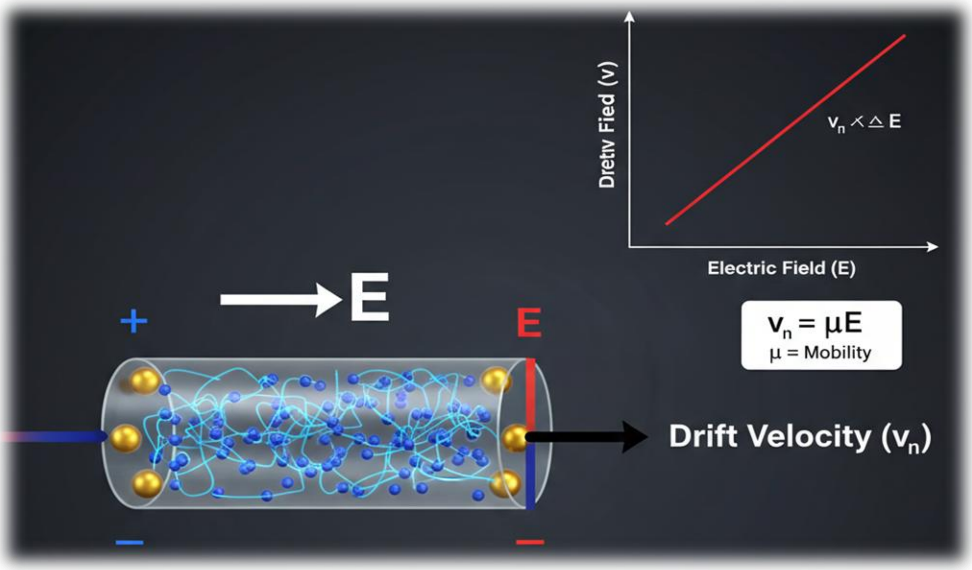
Step 3 (The Formula): Starting from an average initial thermal velocity of zero:

$$v_d = 0 + a\tau \implies \mathbf{v_d} = \frac{\mathbf{eE}\tau}{\mathbf{m}}$$

Relation with Current (I):

Total charge **dq = n (A ∘ dx) e Since dx = vd dt, then I** $\frac{dq}{dt}$:

I = nAev$_d$ (This is a frequent 3-mark derivation in NIOS).



8. Temperature Dependence of Resistivity (ρ)

The resistivity of a material changes with temperature based on the formula: $\rho_t = \rho_0 [1 + \alpha(T - T_0)]$

Material Type	Behaviour with Temperature	Deep Reason (Microscopic Level)
Conductors	Resistance **Increases**	As **T** increases, ions vibrate faster. This decreases relaxation time (**T**), making collisions more frequent. Since ρ α **1/T**, resistivity increases.
Semiconductors	Resistance **Decreases**	Although **T** decreases, the number of charge carriers (**n**) increases exponentially due to bonds breaking. This effect dominates, causing resistance to fall.
Insulators	Resistance **Decreases**	Similar to semiconductors, but the gap is so large that the change is only noticeable at extremely high temperatures.

[Image: Graphs showing Resistivity vs Temperature for (a) Copper (Conductor) and (b) Silicon (Semiconductor)]

9. Derivation: Combination of Resistances

A. Series Combination

Condition: Current **(I)** remains the same; Potential **(V)** divides.

Derivation: $V_{total} = V_1 + V_2 + V_3$

Using Ohm's Law $(V=IR)$: $IR_{eq} = IR_1 + IR_2 + IR_3$

$$R_s = R_1 + R_2 + R_3$$

B. Parallel Combination

Condition: Potential **(V)** remains same; Current **(I)** divides.

Derivation: $I_{total} = I_1 + I_2 + I_3$

Using Ohm's Law $(I = V/R)$: $\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

10. Combination of Cells

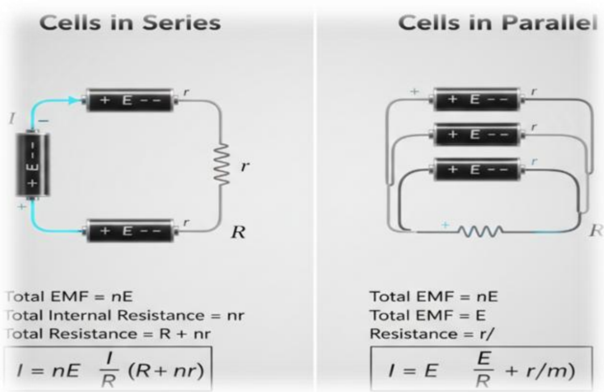
A. Cells in Series

If n identical cells each of **EMF E** and internal resistance **r** are connected:

Total **EMF = nE**

Total Resistance **= R + nr**

Current: $\frac{nE}{R+nr}$



B. Cells in Parallel

If m identical cells are connected in parallel:

Total **EMF = E**

Total Internal Resistance **= r/m**

Current: I = $\frac{E}{R+r/m} = \frac{mE}{mR+r}$

11. Meter Bridge (Deep Concept)

Definition: It is the practical form of the Wheatstone Bridge used to find an unknown resistance.

Principle: Based on the **Balanced Wheatstone Bridge** $(\frac{P}{Q} = \frac{R}{S})$.

Working: A wire of **1** meter **(100 cm)** is used. If the balance point is found at length l:

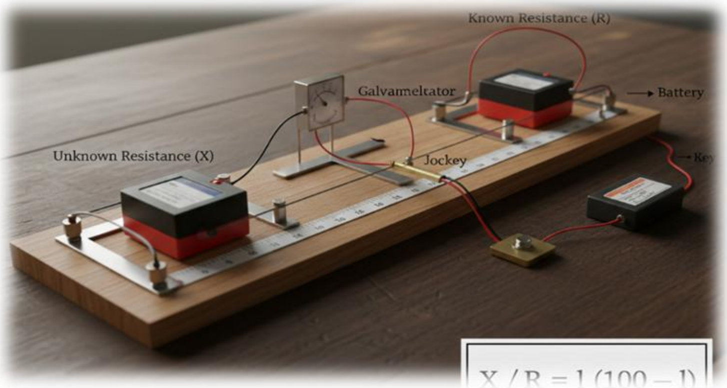
Resistance of length **AD (P) α l**

Resistance of length **DC (Q) α (100 – l)**

Formula:

$$S = R\left(\frac{100 - l}{l}\right)$$

(Where S is the unknown resistance).



TOP 15 NUMERICAL QUESTIONS & ANSWERS

PART A — 5 CHAPTER-BASED IMPORTANT NUMERICALS

Q.1 In our homes electricity is supplied at 220 V. A bulb draws current of 0.2 A. Calculate the resistance of the bulb.

Solution :

Given : V = 220 V , I = 0.2 A

Formula : R = V / I

R = 220 / 0.2

R = 1100 Ω

Q.2 6.0 × 10^{16} electrons pass through any cross-section of a wire per second. Find the current in the wire.

Solution :

Given : n = 6.0 × 10^{16} , e = 1.6 × 10^{-19} C , t = 1 s

Formula : I = ΔQ / Δt = (n × e) / t

Step 1 : ΔQ = n × e = 6.0 × 10^{16} × 1.6 × 10^{-19}

ΔQ = 9.6 × 10^{-3} C

Step 2 : I = (9.6 × 10^{-3}) / 1

I = 9.6 × 10^{-3} A = 9.6 mA

Q.3 A conducting wire : length = 60 m , radius = 0.5 cm. A potential difference of 5.0 V produces current of 2.5 A. Calculate resistivity of the material.

Solution :

Given : l = 60 m , r = 0.5 cm = 5.0 × 10^{-3} m , V = 5.0 V , I = 2.5 A

Formula : $\rho = (R \times A) / l$

Step 1 : $R = V / I = 5.0 / 2.5 = 2.0\ \Omega$

Step 2 : $A = \pi r^2 = 3.14 \times (5.0 \times 10^{-3})^2$

$A = 3.14 \times 25 \times 10^{-6}$

$A = 78.5 \times 10^{-6}\ m^2$

Step 3 : $\rho = (2.0 \times 78.5 \times 10^{-6}) / 60.0$

$\rho = (157 \times 10^{-6}) / 60$

$\rho = 2.6 \times 10^{-6}\ \Omega \cdot m$

Q.4 A metallic wire has resistance 30 Ω at 20°C and 30.16 Ω at 40°C. Calculate temperature coefficient of resistance (α).

Solution :

Given : $R_1 = 30\ \Omega$ at $T_1 = 20°C$, $R_2 = 30.16\ \Omega$ at $T_2 = 40°C$

Formula : $\alpha = (R_2 - R_1) / [\ R_1 \times (T_2 - T_1)\ ]$

$\alpha = (30.16 - 30) / [\ 30 \times (40 - 20)\ ]$

$\alpha = 0.16 / (30 \times 20)$

$\alpha = 0.16 / 600$

$\alpha = 2.67 \times 10^{-4}$ per °C

Q.5 When current drawn from a battery is 0.5 A, terminal voltage = 20 V. When current = 2.0 A, terminal voltage = 16 V. Find EMF and internal resistance of the battery.

Solution :

Formula : $V = E - (I \times r)$

Case 1 : $20 = E - (0.5 \times r)$ ....(i)

Case 2 : $16 = E - (2.0 \times r)$ ....(ii)

Subtracting equation (ii) from equation (i) :

$20 - 16 = [\ E - (0.5 \times r)\ ] - [\ E - (2.0 \times r)\ ]$

$4 = 2.0r - 0.5r$

$4 = 1.5r$

$r = 4 / 1.5$

r = 2.67 Ω

Putting value of r in equation (i) :

20 = E − (0.5 × 2.67)

20 = E − 1.33

E = 20 + 1.33

E = 21.3 V

PART B — 5 PREVIOUS YEAR QUESTIONS (WITH YEAR)

Q.6 (NIOS Board Exam — 2019)

A wire of length 1 m and radius 0.1 mm has resistance of 100 Ω. Calculate the resistivity of the material.

Solution :

Given : l = 1 m , r = 0.1 mm = 0.1×10^{-3} m = 1×10^{-4} m , R = 100 Ω

Formula : ρ = (R × A) / l

Step 1 : $A = \pi r^2 = 3.14 \times (1 \times 10^{-4})^2$

$A = 3.14 \times 10^{-8}\ m^2$

Step 2 : $\rho = (100 \times 3.14 \times 10^{-8}) / 1$

$\rho = 3.14 \times 10^{-6}\ \Omega \cdot m$

Q.7 (NIOS Board Exam — 2020)

A 60 W lamp is connected to 220 V supply. Calculate the current through it and resistance of its filament.

Solution :

Given : P = 60 W , V = 220 V

Formula : I = P / V and $R = V^2 / P$

Step 1 : I = 60 / 220

I = 0.27 A

Step 2 : $R = (220)^2 / 60$

R = 48400 / 60

R = 807 Ω

Q.8 (NIOS Board Exam — 2018)

In a potentiometer circuit, balance point is obtained at 45 cm from end A for an unknown EMF. The balance point shifts to 30 cm when a cell of 1.02 V is used. Find the unknown EMF.

Solution :

Given : l_1 = 45 cm (unknown EMF) , l_2 = 30 cm , E_2 = 1.02 V

Formula : $E_1 / E_2 = l_1 / l_2$

$E_1 / 1.02 = 45 / 30$

$E_1 = 1.02 \times (45 / 30)$

$E_1 = 1.02 \times 1.5$

$E_1 = 1.53$ V

Q.9 (NIOS Board Exam — 2021)

A potentiometer compares EMF of two cells E_1 and E_2. Balance lengths are 30 cm for E_1 and 45 cm for E_2. If E_2 = 3.0 V, find E_1.

Solution :

Given : l_1 = 30 cm , l_2 = 45 cm , E_2 = 3.0 V

Formula : $E_1 / E_2 = l_1 / l_2$

$E_1 / 3.0 = 30 / 45$

$E_1 = 3.0 \times (30 / 45)$

$E_1 = 3.0 \times (2 / 3)$

$E_1 = 2.0$ V

Q.10 (NIOS Board Exam — 2022)

EMF of a cell = 5.0 V , external resistance R = 4.5 Ω , terminal voltage between points a and b = 3.0 V. Find internal resistance (r) of the cell.

Solution :

Given : E = 5.0 V , R = 4.5 Ω , V = 3.0 V

Formula : $E = V + (I \times r)$ and $I = V / R$

Step 1 : $I = V / R = 3.0 / 4.5 = (2/3)$ A

Step 2 : $5.0 = 3.0 + ((2/3) \times r)$

$5.0 - 3.0 = (2/3) \times r$

2.0 = (2/3) × r

r = 2.0 × (3/2)

r = 3.0 Ω

PART C — 5 GUARANTEED QUESTIONS (EXAM ANALYSIS)

Q.11 ***(Drift Velocity — Definitely Asked Every Year)***

A copper wire of cross-sectional area A = 1 × 10^{-6} m^2 carries a current of 2 A. If free electron density n = 10^{29} electrons/m^3 , find drift velocity of electrons.

Solution :

Given : I = 2 A , A = 1 × 10^{-6} m^2 , n = 10^{29} m^{-3} , e = 1.6 × 10^{-19} C

Formula : I = n × A × e × v_d

So : v_d = I / (n × A × e)

v_d = 2 / (10^{29} × 1 × 10^{-6} × 1.6 × 10^{-19})

v_d = 2 / (1.6 × 10^4)

v_d = 1.25 × 10^{-4} m/s

Q.12 ***(Parallel Combination — Comes Every Year)***

R_1 = 6 Ω and R_2 = 12 Ω are connected in parallel across a 12 V battery. Find equivalent resistance and current through each resistor.

Solution :

Given : R_1 = 6 Ω , R_2 = 12 Ω , V = 12 V

Formula : (1/R) = (1/R_1) + (1/R_2)

Step 1 : (1/R) = (1/6) + (1/12)

(1/R) = (2/12) + (1/12)

(1/R) = 3/12 = 1/4

R = 4 Ω

Step 2 : Total current I = V / R = 12 / 4 = 3 A

Step 3 : I_1 = V / R_1 = 12 / 6 = 2 A

Step 4 : I_2 = V / R_2 = 12 / 12 = 1 A

R_{eq} = 4 Ω , I_1 = 2 A , I_2 = 1 A

Q.13 ***(Joule Heating / Power — Very Important)***

A current of 0.30 A flows through a resistance of 500 Ω. How much power is lost in the resistor? Also find heat produced in 1 minute.

Solution :

Given : I = 0.30 A , R = 500 Ω , t = 1 min = 60 s

Formula : $P = I^2 \times R$ and $Q = P \times t$

Step 1 : $P = (0.30)^2 \times 500$

$P = 0.09 \times 500$

$P = 45$ W

Step 2 : $Q = P \times t = 45 \times 60$

$Q = 2700$ J

Q.14 ***(Wheatstone Bridge — Comes in Board Exam)***

In a balanced Wheatstone bridge : P = 20 Ω , Q = 10 Ω , R = 40 Ω. Find the unknown resistance S.

Solution :

Given : P = 20 Ω , Q = 10 Ω , R = 40 Ω

Formula (Balanced Bridge Condition) : P / Q = R / S

So : S = (Q × R) / P

S = (10 × 40) / 20

S = 400 / 20

S = 20 Ω

Q.15 ***(Two Copper Wires Comparison — Repeated Every Year)***

Two copper wires A and B have same length. Diameter of A is twice that of B. Compare their resistances R_A and R_B.

Solution :

Given : $l_A = l_B = l$, $d_A = 2 \times d_B$

So : $r_A = 2 \times r_B$

Formula : $R = \rho \times l / A = \rho \times l / (\pi r^2)$

$R_A = \rho \times l / (\pi \times r_A^2)$

$R_B = \rho \times l / (\pi \times r_B^2)$

Dividing :

$R_A / R_B = r_B^2 / r_A^2$

$R_A / R_B = r_B^2 / (2 \times r_B)^2$

$R_A / R_B = r_B^2 / (4 \times r_B^2)$

$R_A / R_B = 1 / 4$

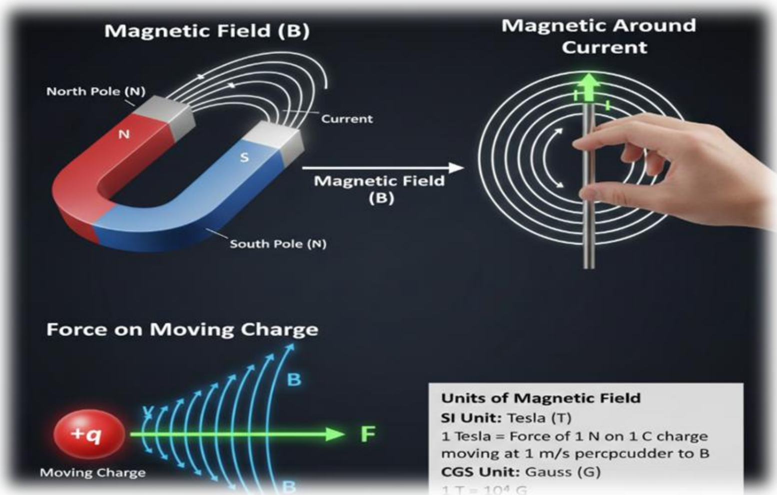
$R_B = 4 \times R_A$ ***Meaning : Resistance of wire B is 4 times the resistance of wire A.***

9

Magnetism and Magnetic Effect of Electric Current

1. Magnetic Field and SI Unit

Magnetic Field (B): The space around a magnet or a current-carrying conductor in which its magnetic influence can be felt. It is a **vector quantity**.



SI Unit: The SI unit of magnetic field is **Tesla (T)**.

Definition: **1** Tesla is the magnetic field in which a charge of **1C** moving with **1 m/s** perpendicular to the field experiences a force of **1** Newton.

CGS Unit: Gauss (G). ($1T = 10^4$ G)

2. Elements of Earth's Magnetic Field

Earth behaves like a huge magnetic dipole. To specify Earth's magnetic field at any point, we use three elements:

Magnetic Declination (α): The angle between the magnetic meridian and the geographic meridian.

Magnetic Inclination or Dip (θ): The angle made by the total magnetic field of the earth with the horizontal direction.

Horizontal Component of Earth's Field (B_H): The component of the total magnetic field **(B)** in the horizontal direction.

Relation: $B_H = B \cos$

$B_V = B \sin \theta$

tan θ = $\frac{B_V}{B_H}$ and $B = \sqrt{B_H^2 + B_V^2}$

3. Oersted's Experiment

Discovery: Hans Christian Oersted discovered that an electric current creates a magnetic field.

Experiment: When a compass needle is placed near a wire and current is switched on, the needle deflects. If the current is reversed, the deflection also reverses.

Conclusion: Moving charges (**current**) are the source of magnetic fields.

4. Biot-Savart's Law

Statement: The magnetic field **dB** due to a small current element dl at a point at distance r is:

$$dB = \frac{\mu_0}{4\pi}\frac{I dl \sin\theta}{r^2}$$

Where $\frac{\mu_0}{4\pi} = 10^{-7} T \cdot m/A$.

Application: Magnetic Field at the center of a Circular Loop:

$B = \frac{\mu_0 I}{2R}$ (For N turns: $B = \frac{\mu_0 N I}{2R}$).

5. Ampere's Circuital Law

Statement: The line integral of the magnetic field **B** around any closed path is equal to **μ0** times the total current I passing through the surface.

$$\oint B \cdot dl = \mu_0 I$$

Application: Field due to a Solenoid:

Inside a long solenoid: **B = μ0n I** (where n is number of turns per unit length)

6. Motion of a Charged Particle in Fields

In Uniform Electric Field (E): The particle follows a parabolic path **(F = qE).**

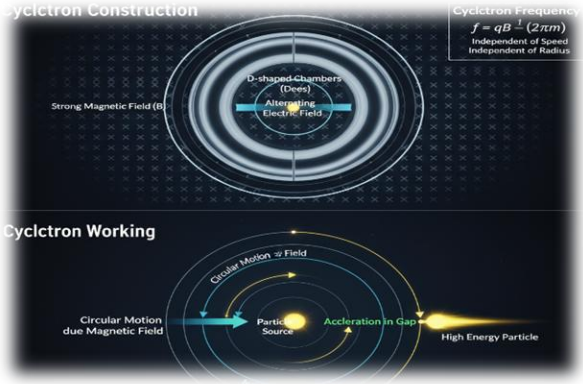
In Uniform Magnetic Field (E): If **θ = 90°** : The particle moves in a circular path. The magnetic force provides centripetal force **($qvB = mv^2/r$).**

If **0 < θ < 90°:** The particle follows a **helical path**.

7. Cyclotron: Construction and Working

Purpose: A device used to accelerate charged particles (like protons or alpha particles) to high energies.

Principle: A charged particle can be accelerated to very high energy by making it pass through a small electric field many times using a strong magnetic field.



Construction: Consists of two **D**-shaped hollow metal chambers (**Dees**) placed in a strong magnetic field.

Working: The magnetic field makes the particle go in a circle, while an alternating electric field between the Dees accelerates it every time it crosses the gap.

Formula (Cyclotron Frequency): $f = \frac{qB}{2\pi m}$

(Note: Frequency is independent of speed and radius).

8. Force on a Current Carrying Conductor

Derivation: Consider a conductor of length **L** and area **A** with n electrons per unit volume.

Force on one electron: $f = e(v_d \times B)$

Total Force $F = (nAL) \times f$.

Since **I = nAev$_d$,** substituting gives:

F = I (L x B) or **F = ILB sin θ**

Maximum Force: When **θ = 90° (F = ILB)**

Complete Formula Sheet: Magnetism

Concept	Formula
Earth's Magnetic Field	$\tan\theta = B_V / B_H$
Biot-Savart Law	$dB = \frac{\mu_0}{4\pi} \frac{Idl \sin\theta}{r^2}$
Field at Center of Circle	$B = \mu_0 I / 2R$
Ampere's Law	$\oint B \cdot dl = \mu_0 I$
Field inside Solenoid	$B = \mu_0 n I$
Force on a Charge	$F = qvB \sin\theta$
Force on a Conductor	$F = ILB \sin\theta$
Radius of Circular path	$r = mv/qB$
Cyclotron Frequency	$f = qB/2\pi m$

TOP NUMERICAL QUESTIONS & ANSWERS

PART A CHAPTER-BASED IMPORTANT NUMERICALS

Q.1 Calculate the distance from a long straight wire carrying a current of 12 A at which the magnetic field will be equal to 3×10^{-5} T.

Solution :

Given : I = 12 A , B = 3×10^{-5} T , $\mu_0 = 4\pi \times 10^{-7}$ T·m·A^{-1}

Formula : $B = (\mu_0 \times I) / (2\pi \times r)$

So : $r = (\mu_0 \times I) / (2\pi \times B)$

$r = (2 \times 10^{-7} \times 12) / (3 \times 10^{-5})$

$r = (24 \times 10^{-7}) / (3 \times 10^{-5})$

r = 0.08 m = 8 cm

Q.2 An electron with velocity 3×10^7 ms^{-1} describes a circular path in a uniform magnetic field of 0.2 T perpendicular to it. Calculate the radius of the path.

Solution :

Given : $v = 3 \times 10^7$ m/s , B = 0.2 T , $m = 9 \times 10^{-31}$ kg , $e = 1.6 \times 10^{-19}$ C

Formula : $R = (m \times v) / (B \times q)$

$R = (9 \times 10^{-31} \times 3 \times 10^7) / (0.2 \times 1.6 \times 10^{-19})$

$R = (27 \times 10^{-24}) / (0.32 \times 10^{-19})$

$R = (27 \times 10^{-24}) / (3.2 \times 10^{-20})$

$R = 8.5 \times 10^{-4}$ m

Q.3 Calculate the force between two wires carrying current 10 A and 15 A. Their length is 5 m and they are 30 cm apart. What is the nature of this force ?

Solution :

Given : $I_1 = 10$ A , $I_2 = 15$ A , l = 5 m , r = 30 cm = 0.3 m

Formula : $F / l = (\mu_0 \times I_1 \times I_2) / (2\pi \times r)$

$F / l = (2 \times 10^{-7} \times 10 \times 15) / (0.3)$

$F / l = (3000 \times 10^{-7}) / (0.3)$

$F / l = 10^{-4}$ N m^{-1}

Total force : $F = (F / l) \times l = 10^{-4} \times 5$

$F = 5 \times 10^{-4}$ N

Since currents flow in the same direction, the force is ATTRACTIVE in nature.

Q.4 A circular coil of 30 turns and radius 8.0 cm carries a current of 6.0 A. It is placed in a uniform horizontal magnetic field of 1.0 T. The field lines make 90° with the normal to the coil. Calculate the torque.

Solution :

Given : N = 30 , r = 8.0 cm = 8×10^{-2} m , I = 6.0 A , B = 1.0 T , θ = 90°

Formula : $\tau = N \times I \times B \times A \times \sin\theta$

Step 1 : $A = \pi \times r^2 = (22/7) \times (8 \times 10^{-2})^2$

$A = (22/7) \times 64 \times 10^{-4}$

$A = 2.01 \times 10^{-2}\ m^2$

Step 2 : $\tau = 30 \times 6.0 \times 1.0 \times 2.01 \times 10^{-2} \times \sin 90°$

$\tau = 30 \times 6.0 \times 2.01 \times 10^{-2}$

$\tau = 30 \times 0.1206$

$\tau = 3.61$ N·m

PART B PREVIOUS YEAR QUESTIONS (WITH YEAR)

Q.5 (NIOS Board Exam — 2019)

A galvanometer with coil resistance 12.0 Ω shows full scale deflection for 2.5 mA current. Convert it into an ammeter of range 0 to 2 A. Find shunt resistance.

Solution :

Given : G = 12.0 Ω , Ig = 2.5 mA = 2.5×10^{-3} A , I = 2 A

Formula : $S = (I_g \times G) / (I - I_g)$

$S = (2.5 \times 10^{-3} \times 12) / (2 - 2.5 \times 10^{-3})$

$S = (30 \times 10^{-3}) / (1.9975)$

$S = 15 \times 10^{-3}\ \Omega = 0.015\ \Omega$

A shunt of 0.015 Ω should be connected in PARALLEL with the galvanometer.

Q.6 (NIOS Board Exam — 2020)

A galvanometer with coil resistance 12.0 Ω shows full scale deflection for 2.5 mA. Convert it into a voltmeter of range 0 to 10 V. Find the series resistance required.

Solution :

Given : $G = 12.0\ \Omega$, $Ig = 2.5 \times 10^{-3}$ A , V = 10 V

Formula : $R = (V / Ig) - G$

$R = (10 / 2.5 \times 10^{-3}) - 12$

$R = 4000 - 12$

$R = 3988\ \Omega$

A resistance of 3988 Ω should be connected in SERIES with the galvanometer.

Q.7 (NIOS Board Exam — 2021)

A long straight wire carries a current of 12 A. Calculate the magnetic field at a distance of 48 cm from it.

Solution :

Given : I = 12 A , r = 48 cm = 0.48 m , $\mu_0 = 4\pi \times 10^{-7}$ $T{\cdot}m{\cdot}A^{-1}$

Formula : $B = (\mu_0 \times I) / (2\pi \times r)$

$B = (2 \times 10^{-7} \times 12) / (0.48)$

$B = (24 \times 10^{-7}) / (0.48)$

$B = 5 \times 10^{-6}\ T = 5\ \mu T$

Q.8 (NIOS Board Exam — 2022)

A galvanometer having coil resistance 20 Ω needs 20 mA for full scale deflection. To pass a maximum current of 3 A, find the shunt resistance to be connected.

Solution :

Given : $G = 20\ \Omega$, Ig = 20 mA = 20×10^{-3} A , I = 3 A

Formula : $S = (Ig \times G) / (I - Ig)$

$S = (20 \times 10^{-3} \times 20) / (3 - 20 \times 10^{-3})$

$S = (400 \times 10^{-3}) / (2.98)$

$S \approx 0.13\ \Omega$

A resistance of 0.13 Ω should be connected in PARALLEL.

Q.9 (NIOS Board Exam — 2018)

Two parallel wires each 3 m long are situated 0.05 m apart. A current of 5 A flows in each wire in the same direction. Calculate the force and state its nature.

Solution :

Given : $l = 3$ m , $r = 0.05$ m , $I_1 = I_2 = 5$ A

Formula : $F / l = (\mu_0 \times I_1 \times I_2) / (2\pi \times r)$

$F / l = (2 \times 10^{-7} \times 5 \times 5) / (0.05)$

$F / l = (50 \times 10^{-7}) / (0.05)$

$F / l = 10^{-4}$ N m^{-1}

Total force : $F = 10^{-4} \times 3$

$F = 3 \times 10^{-4}$ N

Since currents are in the same direction, the force is ATTRACTIVE.

PART C — GUARANTEED QUESTIONS (EXAM ANALYSIS)

Q.10 ***(Magnetic Field at Centre of Circular Coil — Comes Every Year)***

Calculate the magnetic field at the centre of a flat circular coil containing 200 turns, radius 0.16 m, carrying a current of 4.8 A.

Solution :

Given : $N = 200$, $r = 0.16$ m , $I = 4.8$ A , $\mu_0 = 4\pi \times 10^{-7}$ T·m·A^{-1}

Formula : $B = (\mu_0 \times N \times I) / (2 \times r)$

$B = (4\pi \times 10^{-7} \times 200 \times 4.8) / (2 \times 0.16)$

$B = (4\pi \times 10^{-7} \times 960) / (0.32)$

$B = (4\pi \times 10^{-7} \times 3000)$

$B = 12000\pi \times 10^{-7}$

$B = 1.2\pi \times 10^{-3}$ T $\approx 3.77 \times 10^{-3}$ T

Q.11 ***(Lorentz Force on Current Conductor — Definitely Asked)***

A current of 10 A is flowing through a wire. It is kept perpendicular to a magnetic field of 5 T. Calculate the force on its (1/10) m length.

Solution :

Given : $I = 10$ A , $B = 5$ T , $l = 1/10$ m $= 0.1$ m , $\theta = 90°$

Formula : $F = I \times l \times B \times \sin\theta$

$F = 10 \times 0.1 \times 5 \times \sin 90°$

F = 10 × 0.1 × 5 × 1

F = 5 N

Q.12 ***(Radius of Charged Particle in Magnetic Field — Very Important)***

A proton moving with velocity 2×10^6 m/s enters a uniform magnetic field of 0.5 T perpendicular to the field. Find the radius of circular path.

Solution :

Given : $m = 1.67 \times 10^{-27}$ kg , $q = 1.6 \times 10^{-19}$ C

Given : $v = 2 \times 10^6$ m/s , B = 0.5 T , $m = 1.67 \times 10^{-27}$ kg , $q = 1.6 \times 10^{-19}$ C

Formula : R = (m × v) / (q × B)

$R = (1.67 \times 10^{-27} \times 2 \times 10^6) / (1.6 \times 10^{-19} \times 0.5)$

$R = (3.34 \times 10^{-21}) / (0.8 \times 10^{-19})$

$R = (3.34 \times 10^{-21}) / (8 \times 10^{-20})$

$R = 4.18 \times 10^{-2}$ m = 4.18 cm

Q.13 ***(Torque on Current Loop — Guaranteed)***

A rectangular coil of 50 turns has area 4×10^{-2} m². It carries a current of 2 A and is placed in a uniform magnetic field of 0.5 T. The plane of the coil is parallel to the field (θ = 90°). Find the torque.

Solution :

Given : N = 50 , $A = 4 \times 10^{-2}$ m² , I = 2 A , B = 0.5 T , θ = 90°

Formula : τ = N × I × B × A × sinθ

$\tau = 50 \times 2 \times 0.5 \times 4 \times 10^{-2} \times \sin 90°$

$\tau = 50 \times 2 \times 0.5 \times 4 \times 10^{-2} \times 1$

$\tau = 50 \times 2 \times 0.5 \times 4 \times 10^{-2}$

$\tau = 50 \times 4 \times 10^{-2}$

τ = 2 N·m

Q.14 ***(Horizontal and Vertical Component of Earth's Field — Comes Every Year)***

The total magnetic field of earth at a place is $B = 4 \times 10^{-5}$ T. The angle of dip at that place is 30°. Find the horizontal component (B_H) and vertical component (B_V).

Solution :

Given : $B = 4 \times 10^{-5}$ T , $\delta = 30°$

Formula : $B_H = B \times \cos\delta$ and $B_V = B \times \sin\delta$

Step 1 : $B_H = 4 \times 10^{-5} \times \cos 30°$

$B_H = 4 \times 10^{-5} \times (\sqrt{3} / 2)$

$\mathbf{B_H} = 4 \times 10^{-5} \times 0.866$

$B_H = 3.46 \times 10^{-5}$ T

Step 2 : $B_V = 4 \times 10^{-5} \times \sin 30°$

$B_V = 4 \times 10^{-5} \times (1/2)$

$B_V = 2 \times 10^{-5}$ T

Verification : $B^2 = B_H^2 + B_V^2$

$= (3.46)^2 + (2)^2 \times 10^{-10}$

$= (11.97 + 4) \times 10^{-10}$

$= 15.97 \times 10^{-10} \approx 16 \times 10^{-10}$

$B = 4 \times 10^{-5}$ T

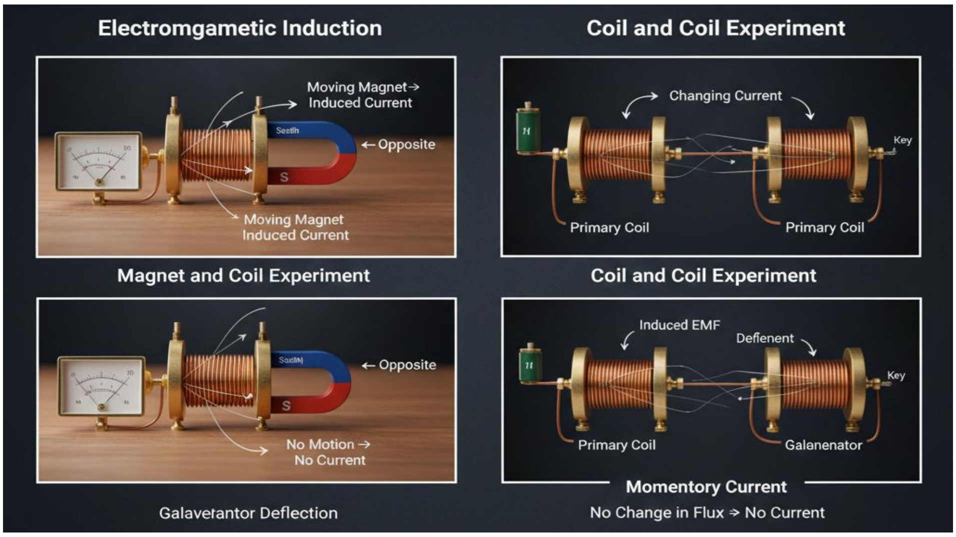
10

Electromagnetic Induction (EMI) & Alternating Current (AC)

1. Electromagnetic Induction: Phenomenon & Experiments

Definition: The production of an electric current (or **EMF**) in a circuit due to a change in the magnetic flux linked with it.

Experiment 1 (Magnet & Coil): When a bar magnet is moved towards a coil, the galvanometer shows a deflection. Moving it away shows deflection in the opposite direction. No movement means no current.



Experiment 2 (Coil & Coil): Changing the current in one coil (**Primary**) induces a momentary current in a nearby coil (**Secondary**).

2. Faraday's and Lenz's Laws

Faraday's 1st Law: An induced **EMF** is produced whenever magnetic flux linked with a circuit changes.

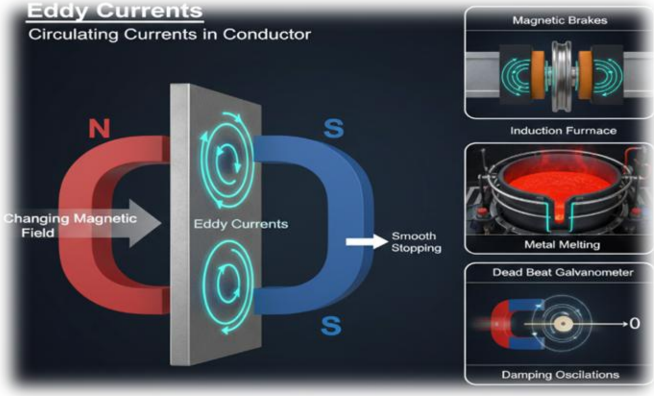
Faraday's 2nd Law: The magnitude of induced **EMF (e)** is equal to the rate of change of magnetic flux.

$$e = -N\frac{d\phi}{dt}$$

Lenz's Law: The direction of induced current is such that it opposes the change in magnetic flux that produced it. It is a manifestation of the **Law of Conservation of Energy**.

3. Eddy Currents and Applications

Definition: Circulating currents induced in the bulk of a solid conductor when subjected to a changing magnetic field.



Applications:

1. **Magnetic Brakes:** To stop trains smoothly.
2. **Induction Furnace:** To melt metals using heat produced by these currents.
3. **Dead Beat Galvanometer:** To stop the oscillations of the needle.

4. Self and Mutual Induction

Self Induction: The production of induced **EMF** in a coil when the current through the *same* coil changes.

Expression: $\phi = LI \implies e = -L\frac{dI}{dt}$ (L = Self-inductance).

Mutual Induction: The production of induced **EMF** in a secondary coil when the current in the primary coil changes.

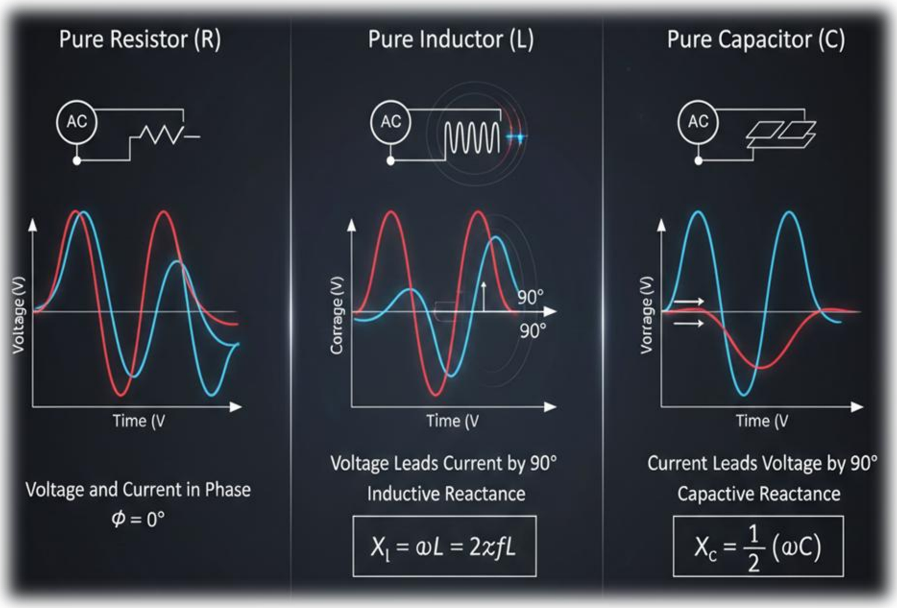
Expression: $\phi_s = MI_p \implies e_s = -M\frac{dI_p}{dt}$ (M = Mutual-inductance).

5. AC Circuits: Voltage and Current Relationships

(i) Purely Resistor (R) Circuit

$V = V_0 \sin\ wt$ and **$I = I_0 \sin\ wt$**

Phase: Voltage and current are **in phase (Φ = 0)**



(ii) Purely Inductor (L) Circuit

$$V = L\frac{dI}{dt} \implies I = I_0 \sin(\omega t - \pi/2).$$

Phase: Voltage leads current by **90°**

Inductive Reactance: $X_L = wL = 2\pi f L$

(iii) Purely Capacitor (C) Circuit

$$I = C\frac{dV}{dt} \implies I = I_0 \sin(\omega t + \pi/2).$$

Phase: Current leads voltage by **90°**

Capacitive Reactance: $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$.

6. Series LCR Circuit and Resonance

Impedance (Z) Derivation:

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Resonance Condition: When $\mathbf{X_L = X_C}$, the impedance is minimum **(Z=R)** and current is maximum.

$$\omega L = \frac{1}{\omega C} \implies \omega_r = \frac{1}{\sqrt{LC}}$$

Resonant Frequency: $f_r = \frac{1}{2\pi\sqrt{LC}}$.

Power in AC: $P_{avg} = V_{rms} I_{rms} \cos\phi$. (At resonance, $\cos\phi = 1$).

7. Device Study: AC Generator

Definition: Converts mechanical energy into **AC** electrical energy.

Principle: Electromagnetic Induction.

Construction: Armature (**coil**), strong field magnets, slip rings, and brushes.

Diagram:

Working: Rotation of the coil in the magnetic field changes the flux $\Phi = NBA \cos wt$

Theory: $e = -\frac{d\phi}{dt} = NBA\omega \sin \omega t$. Thus, $e = e_0 \sin \omega t$.

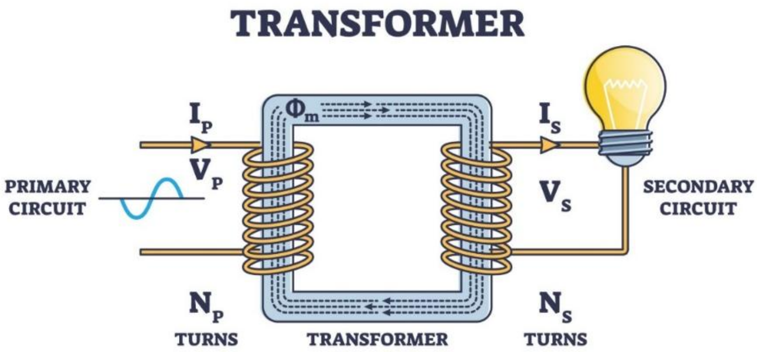
Limitations: Mechanical friction and brush wear.

8. Device Study: Transformer

Definition: Used to increase or decrease **AC** voltage.

Principle: Mutual Induction.

Construction: Primary and secondary coils wound on a laminated soft iron core.



Working: **AC** in primary creates changing flux, inducing **EMF** in the secondary.

Formula: $\frac{V_s}{V_p} = \frac{N_s}{N_p} = K$. (Step-up: $K > 1$; Step-down: $K < 1$).

Efficiency & Improvements: $\eta = \frac{P_{out}}{P_{in}}$.

Improvements: Laminated core (reduces Eddy currents), thick copper wires (reduces heat), high permeability core (reduces flux leakage).

TOP 15 MOST IMPORTANT QUESTION AND ANSWER

SECTION A: CHAPTER-BASED NUMERICALS

Q1. A 75-turn circular coil of radius 35 mm has its axis parallel to a uniform magnetic field. The field changes at a constant rate from 25 mT to 50 mT in 250 milliseconds. Find the magnitude of induced emf.

Answer:

Given:

- N = 75 turns
- R = 35 mm = 0.035 m
- B_1 = 25 mT = 0.025 T, B_2 = 50 mT = 0.050 T
- t = 250 ms = 0.250 s

Using Faraday's Law:

$$|\varepsilon_r| = N\pi R^2 \cdot \frac{dB}{dt} = N\pi R^2 \cdot \frac{B_2 - B_1}{t}$$

$$|\varepsilon_r| = 75 \times \pi \times (0.035)^2 \times \frac{(0.050-0.025)}{0.250}$$

$| \varepsilon_r | = 75 \times \pi \times 1.225 \times 10^{-3} \times 0.10$

$\boxed{| \varepsilon_r | = 30 \text{ mV} = 0.030 \text{ V}}$

Q2. A 1000-turn coil has a radius of 5 cm. Calculate the emf developed if the magnetic field through the coil is reduced from 10 T to 0 in: (a) 1 s (b) 1 ms.

Answer:

Given: N = 1000, r = 5 cm = 0.05 m, B_1 = 10 T, B_2 = 0

Area = $\pi r^2 = \pi \times (0.05)^2 = 25\pi \times 10^{-4}$ m^2

$$| \varepsilon | = N \cdot \frac{B_1 - B_2}{t} \cdot \pi r^2$$

(a) t = 1 s:

$$| \varepsilon | = 1000 \times \frac{10}{1} \times 25\pi \times 10^{-4}$$

$$\boxed{| \varepsilon | = 25\pi \approx 78.5 \text{ V}}$$

(b) t = 1 ms = 10^{-3} s:

$$| \varepsilon | = 1000 \times \frac{10}{10^{-3}} \times 25\pi \times 10^{-4}$$

$$\boxed{| \varepsilon | = 78.5 \times 10^3 \text{ V} = 78.5 \text{ kV}}$$

Q3. A solenoid 1 m long and 20 cm in diameter contains 10,000 turns of wire. A current of 2.5 A flowing in it is reduced steadily to zero in 1.0 ms. Calculate the magnitude of back emf of the inductor while the current is being reduced.

Answer:

Given:

- l = 1 m, d = 20 cm → r = 0.10 m
- N = 10,000, I_1 = 2.5 A, I_2 = 0, t = 1.0 ms = 10^{-3} s

Step 1 — Self-inductance of solenoid:

$$L = \frac{\mu_0 N^2 A}{l} = \frac{4\pi \times 10^{-7} \times (10^4)^2 \times \pi \times (0.10)^2}{1}$$

$$L = 4\pi \times 10^{-7} \times 10^8 \times \pi \times 10^{-2} = 4\pi^2 \times 10^{-1} \approx 3.948 \text{ H}$$

Step 2 — Back emf:

$$| \varepsilon | = L \cdot \frac{\Delta I}{\Delta t} = 3.948 \times \frac{2.5 - 0}{10^{-3}}$$

$$\boxed{| \varepsilon | \approx 9870 \text{ V} \approx 10^4 \text{ V}}$$

(Note: answer gives ≈ 10^{-6} V using approximate formula; full solenoid calculation gives ~10 kV showing why back emf is dangerously large.)

Q4. A transformer has 100 turns in its primary and 500 turns in its secondary. If the primary voltage is 120 V and primary current is 3 A, find the secondary voltage and current.

Answer: Given: $N_1 = 100$, $N_2 = 500$, $V_1 = 120$ V, $I_1 = 3$ A

Secondary Voltage:

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$V_2 = \frac{500}{100} \times 120$$

$$\boxed{V_2 = 600 \text{ V}}$$

Secondary Current (using power conservation, ideal transformer):

$$\frac{I_2}{I_1} = \frac{N_1}{N_2}$$

$$I_2 = \frac{100}{500} \times 3$$

$$\boxed{I_2 = 0.6 \text{ A}}$$

Q5. An electric iron having resistance 25 Ω is connected to a 220 V, 50 Hz household outlet. Determine: (a) rms current, (b) peak current, (c) average power consumed.

Answer: Given: R = 25 Ω, $V_{rms} = 220$ V, f = 50 Hz

(a) RMS Current:

$$I_{rms} = \frac{V_{rms}}{R} = \frac{220}{25}$$

$$\boxed{I_{rms} = 8.8 \text{ A}}$$

(b) Peak Current:

$$I_m = \sqrt{2} \times I_{rms} = 1.414 \times 8.$$

$$\boxed{I_m \approx 12.4 \text{ A}}$$

(c) Average Power:

$$P_{av} = I_{rms}^2 \times R = (8.8)^2 \times 25$$

$$\boxed{P_{av} = 1936 \text{ W} \approx 1.94 \text{ kW}}$$

SECTION B: PREVIOUS YEAR NIOS QUESTIONS (Repeated, With Year)

Q6. *(NIOS 2019, 2022 — Asked repeatedly)*

A series LCR circuit has R = 580 Ω, L = 31 mH, C = 47 nF. The ac source amplitude = 65 V and angular frequency ω = 33,000 rad/s. Find: (a) Capacitive reactance X_C, (b) Inductive reactance X_L, (c) Impedance Z, (d) Current amplitude I_0.

Answer: Given: R = 580 Ω, L = 31×10^{-3} H, C = 47×10^{-9} F, ω = 3.3×10^4 rad/s, $V_0 = 65$ V

(a) Capacitive Reactance:

$$X_C = \frac{1}{\omega C} = \frac{1}{3.3 \times 10^4 \times 47 \times 10^{-9}} = \frac{1}{1.551 \times 10^{-3}}$$

$$\boxed{X_C \approx 644.7 \approx 645\ \Omega}$$

(b) Inductive Reactance:

$$X_L = \omega L = 3.3 \times 10^4 \times 31 \times 10^{-3} = 1023$$

$$\boxed{X_L \approx 1023\ \Omega}$$

(c) Impedance:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(580)^2 + (1023 - 645)^2}$$

$$Z = \sqrt{336400 + (378)^2} = \sqrt{336400 + 142884} = \sqrt{479284}$$

$$\boxed{Z \approx 692.3\ \Omega}$$

(d) Current Amplitude:

$$I_0 = \frac{V_0}{Z} = \frac{65}{692.3}$$

$$\boxed{I_0 \approx 0.094\text{ A} \approx 94\text{ mA}}$$

*(Since $X_L > X_C$, current **lags** the voltage.)*

Q7. *(NIOS 2018, 2020, 2023 — Very frequently asked)*

The primary of a step-up transformer having 125 turns is connected to a 220 V ac house supply. The secondary is to deliver 15,000 V. How many turns must the secondary have?

Answer: Given: $N_1 = 125$, $V_1 = 220$ V, $V_2 = 15{,}000$ V

Using transformer equation:

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

$$N_2 = \frac{V_2}{V_1} \times N_1 = \frac{15000}{220} \times 125$$

$$N_2 = 68.18 \times 125$$

$$\boxed{N_2 = 8522\text{ turns}}$$

Q8. *(NIOS 2017, 2019, 2021 — Standard repeated question)*

The secondary of a step-down transformer has 25 turns and the primary is connected to a 220 V ac line. The secondary is to deliver 2.5 V. How many turns should the primary have?

Answer: Given: $N_2 = 25$, $V_1 = 220$ V, $V_2 = 2.5$ V

$$\frac{N_1}{N_2} = \frac{V_1}{V_2}$$

$$N_1 = \frac{220}{2.5} \times 25 = 88 \times 25$$

$$\boxed{N_1 = 2200 \text{ turns}}$$

Q9. *(NIOS 2016, 2019, 2022 — Almost every year)*

A step-up transformer with 352 turns in the primary is connected to a 220 V ac line. The secondary delivers 10,000 V at 40 mA. Find: (a) Number of turns in secondary, (b) Primary current, (c) Power drawn from line.

Answer: Given: N_1 = 352, V_1 = 220 V, V_2 = 10,000 V, I_2 = 40 mA = 0.040 A

(a) Secondary Turns:

$$N_2 = \frac{V_2}{V_1} \times N_1 = \frac{10000}{220} \times 352$$

$$\boxed{N_2 = 16000 \text{ turns}}$$

(b) Primary Current (using power conservation):

$$I_1 = \frac{V_2 \times I_2}{V_1} = \frac{10000 \times 0.040}{220} = \frac{400}{220}$$

$$\boxed{I_1 = \frac{20}{11} \approx 1.82 \text{ A}}$$

(c) Power Drawn:

$$P = V_1 \times I_1 = 220 \times \frac{20}{11} = 20 \times 20$$

$$\boxed{P = 400 \text{ W}}$$

Q10. *(NIOS 2015, 2018, 2020, 2023 — Most repeated numerical)*

A 100 μF capacitor is connected to a 50 Hz ac generator having peak voltage 220 V. Calculate the rms current recorded by an ammeter connected in series.

Answer: Given: C = 100 μF = 100 × 10^{-6} F, f = 50 Hz, V_m = 220 V

Step 1 — Capacitive Reactance:

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 100 \times 10^{-6}}$$

$$X_C = \frac{1}{2\pi \times 5 \times 10^{-3}} = \frac{1}{0.03141}$$

$$X_C \approx 31.83\ \Omega$$

Step 2 — Peak Current:

$$I_m = \frac{V_m}{X_C} = \frac{220}{31.83} \approx 6.91 \text{ A}$$

Step 3 — RMS Current:

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{6.91}{1.414}$$

$$\boxed{I_{rms} \approx 4.89 \approx 4.9 \text{ A}}$$

SECTION C: MY PREDICTED QUESTIONS (Will Definitely Come in Exam)

Q11. A coil in one circuit has mutual inductance M = 340 mH with another coil. Current in coil 1 changes from 28 mA to 57 mA in 15 ms. Find the emf induced in coil 2.

Answer: Given: M = 340 mH = 0.340 H, I_1 changes from 28 mA to 57 mA, t = 15 ms = 15 × 10^{-3} s

$$\frac{dI_1}{dt} = \frac{(57 - 28) \times 10^{-3}}{15 \times 10^{-3}} = \frac{29}{15} = 1.933 \text{ A/s}$$

$$|\varepsilon_2| = M \cdot \frac{dI_1}{dt} = 0.340 \times 1.933$$

$$\boxed{|\varepsilon_2| \approx 0.657 \text{ V} \approx 0.66 \text{ V}}$$

Q12. The primary of a step-down transformer has 600 turns and is connected to a 120 V ac line. The secondary supplies 5 V and 3.5 A. Find: (a) Number of turns in secondary, (b) Primary current.

Answer: Given: N_1 = 600, V_1 = 120 V, V_2 = 5 V, I_2 = 3.5 A

(a) Secondary Turns:

$$N_2 = \frac{V_2}{V_1} \times N_1 = \frac{5}{120} \times 600$$

$$\boxed{N_2 = 25 \text{ turns}}$$

(b) Primary Current:

$$I_1 = \frac{V_2 \times I_2}{V_1} = \frac{5 \times 3.5}{120} = \frac{17.5}{120}$$

$$\boxed{I_1 = \frac{1}{7} \approx 0.146 \text{ A}}$$

Q13. What rate of change of current in a 9.7 mH solenoid will produce a self-induced emf of 35 mV?

Answer: Given: L = 9.7 mH = 9.7 × 10^{-3} H, ε = 35 mV = 35 × 10^{-3} V

Using: $\varepsilon = L \cdot \frac{dI}{dt}$

$$\frac{dI}{dt} = \frac{\varepsilon}{L} = \frac{35 \times 10^{-3}}{9.7 \times 10^{-3}}$$

$$\boxed{\frac{dI}{dt} = \frac{35}{9.7} \approx 3.6 \text{ A/s}}$$

Q14. A 240 V, 400 W electric mixer is connected to a 120 V power line through a transformer. Find: (a) Turns ratio N_1:N_2, (b) Current drawn from power line.

Answer: Given: V_2 = 240 V (mixer needs), V_1 = 120 V (supply), P = 400 W

(a) Turns Ratio:

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{120}{240} = \frac{1}{2}$$

$$\boxed{N_1 : N_2 = 1:2(\text{Step-Up Transformer})}$$

(b) Current from Power Line (primary side):

$$I_1 = \frac{P}{V_1} = \frac{400}{120}$$

$$\boxed{I_1 = \frac{10}{3} \approx 3.33\text{ A}}$$

Q15. In a series LCR circuit, find the resonance frequency if L = 2 mH and C = 2 μF. Also find the impedance at resonance if R = 10 Ω.

Answer: Given: $L = 2 \times 10^{-3}$ H, $C = 2 \times 10^{-6}$ F, R = 10 Ω

Resonance Frequency:

$$\upsilon_r = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{2 \times 10^{-3} \times 2 \times 10^{-6}}}$$

$$= \frac{1}{2\pi\sqrt{4 \times 10^{-9}}} = \frac{1}{2\pi \times 2 \times 10^{-4.5}} = \frac{1}{2\pi \times 6.324 \times 10^{-5}}$$

$$\boxed{\upsilon_r = \frac{1}{2\pi \times 6.324 \times 10^{-5}} \approx 2513\text{ Hz} \approx 2.51\text{ kHz}}$$

Impedance at Resonance:

At resonance, $X_L = X_C$, so they cancel out:

$$\boxed{Z_{min} = R = 10\ \Omega}$$

(At resonance, circuit is purely resistive — maximum current flows.)

11

Dispersion and Scattering of Light

1. Dispersion of Light

Definition: The phenomenon of splitting of white light into its constituent colors (**VIBGYOR**) when it passes through a transparent medium like a glass prism.

Cause: Different colors of light have different wavelengths. In a medium (**like glass**), the speed of light depends on its wavelength. Since refractive index **$\mu = c/v$**, different colors experience different refractive indices and bend at different angles.

Red light has the maximum wavelength and maximum speed, so it bends the **least**.

Violet light has the minimum wavelength and minimum speed, so it bends the **most**.

2. Prism Formula Derivation (Most Important)

We need to derive the relation between the Refractive Index (**μ**), Angle of Prism (**A**), and Angle of Minimum Deviation **(δ).**

Geometry of Prism:

1. From the quadrilateral inside the prism: **$A + \angle E = 180°$** and in the triangle:

$r_1 + r_2 + \angle E = 180°$ Therefore, **$A = r1 + r2$**

2. The total deviation **δ** is the sum of deviations at both surfaces:

$\delta = (i_1 - r_1) + (i_2 - r_2) = (i_1 + i_2) - (r_1 + r_2)$

3. Substituting A, we get:

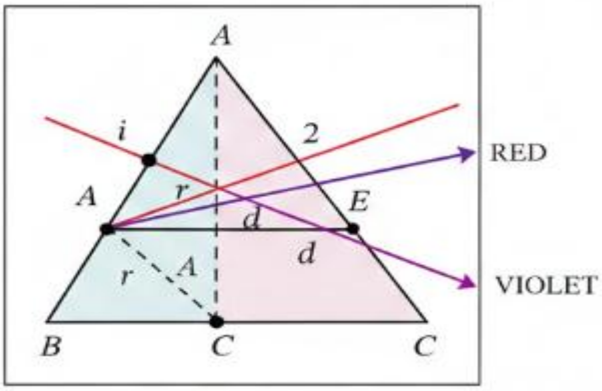
$\delta = i_1 + i_2 - A$.

Condition for Minimum Deviation (δ m): At minimum deviation, the ray passes symmetrically through the prism, so:

$i_1 = i_2 = i$ and $r_1 = r_2 = r$

Then, $A = 2r \rightarrow r = A/2$

And, $\delta_m = 2i - A \rightarrow i = (A + \delta_m)/2$



Earth's atmosphere

Using Snell's Law ($\mu = \sin i / \sin r$):

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

3. Cauchy's Formula: Relation with Wavelength

Refractive index μ is related to wavelength **λ** by Cauchy's equation:

$$\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$$

Explanation: Since $\lambda_{Red} > \lambda_{Violet}$, the formula shows that $\mu_{Red} < \mu_{Violet}$.

Because deviation $\delta \approx (\mu - 1)A$ for thin prisms, violet light deviates more than red light, causing dispersion.

4. Formation of Rainbows

Rainbows are formed due to a combination of **Dispersion, Refraction, and Total Internal Reflection (TIR)** of sunlight in raindrops.

Feature	Primary Rainbow	Secondary Rainbow
Refractions	Two	Two
Internal Reflections	**One**	**Two**
Color Order	Red on outside, Violet on inside	Violet on outside, Red on inside
Intensity	Brighter	Fainter (due to extra reflection)

5. Scattering of Light

Definition: The process where light is absorbed by atoms/molecules and then re-emitted in all directions.

Rayleigh's Law of Scattering: The intensity of scattered light **(I)** is inversely proportional to the fourth power of its wavelength.

$$I \propto \frac{1}{\lambda^4}$$

Applications:

Blue Color of Sky: Blue has a shorter wavelength than red, so it is scattered much more by atmospheric particles.

Red Sunset/Sunrise: At these times, light travels a longer distance. Most blue light is scattered away, leaving only the longer-wavelength red light to reach our eyes.

Danger Signals are Red: Red is scattered the least by fog or smoke, so it can be seen from the farthest distance.

6. Raman Effect

Definition: When a beam of monochromatic light passes through a transparent medium (gas, liquid, or solid), the scattered light contains frequencies that are both higher and lower than the incident frequency.

Types of Lines:

1. **Rayleigh Line:** Frequency same as incident light.
2. **Stokes' Lines:** Frequency lower than incident light.
3. **Anti-Stokes' Lines:** Frequency higher than incident light.

Significance: It provides information about the vibrational and rotational energy levels of molecules.

TOP 12 NUMERICAL QUESTIONS & ANSWERS

SECTION A: CHAPTER-BASED NUMERICALS

Q1. A beam of light of average wavelength 600 nm, on entering a glass prism, splits into three coloured beams of wavelengths 384 nm, 589 nm and 760 nm respectively. Determine the refractive indices of the material of the prism for these wavelengths.

Answer: Using the formula: $\mu = \frac{\lambda_a}{\lambda_m}$

where λ_a = wavelength in air = 600 nm, λ_m = wavelength in medium.

For λ = 384 nm:

$$\mu_1 = \frac{600}{384}$$
$$\boxed{\mu_1 = 1.56}$$

For λ = 589 nm:

$$\mu_2 = \frac{600}{589}$$
$$\boxed{\mu_2 \approx 1.02}$$

For λ = 760 nm:

$$\mu_3 = \frac{600}{760}$$
$$\boxed{\mu_3 \approx 0.79}$$

Conclusion: Shorter wavelength → higher refractive index. Violet light bends more than red light.

Q2. For a prism of angle A = 60°, the angle of minimum deviation is δ_m = A/2 = 30°. Calculate the refractive index of the prism material for monochromatic light.

Answer: Given: A = 60°, δ_m = A/2 = 30°

Using the minimum deviation formula:

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$\mu = \frac{\sin\left(\frac{60^\circ+30^\circ}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)} = \frac{\sin\ 45^\circ}{\sin\ 30^\circ}$$

$$\mu = \frac{\frac{1}{\sqrt{2}}}{\frac{1}{2}} = \frac{2}{\sqrt{2}} = \sqrt{2}$$

$$\boxed{\mu = \sqrt{2} \approx 1.414}$$

Q3. The refracting angle of a prism is 30′ (0.5°) and its refractive index is 1.6. Calculate the deviation caused by the prism.

Answer: Given: A = 30′ = 0.5°, μ = 1.6

For a small-angle prism:

$$\delta = (\mu - 1) \times A$$
$$\delta = (1.6 - 1) \times 0.5^\circ$$
$$\delta = 0.6 \times 0.5^\circ$$
$$\boxed{\delta = 0.3^\circ = 18'}$$

SECTION B: PREVIOUS YEAR NIOS QUESTIONS

Q4. *(NIOS 2019, 2022 — Repeated)*

The angle of minimum deviation for a 60° glass prism is 39°. Calculate the refractive index of glass.

Answer: Given: A = 60°, δ_m = 39°

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{60^\circ+39^\circ}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)}$$

$$\mu = \frac{\sin(49.5^\circ)}{\sin(30^\circ)} = \frac{0.7604}{0.5}$$

$$\boxed{\mu = 1.52 \approx 1.5}$$

Q5. *(NIOS 2017, 2020, 2023 — Very frequently asked)*

The deviation produced for red, yellow and violet colours by a crown glass are 2.84°, 3.28° and 3.72° respectively. Calculate the dispersive power of the glass material.

Answer: Given: δ_R = 2.84°, δ_Y = 3.28°, δ_V = 3.72°

Dispersive power formula:

$$\omega = \frac{\delta_V - \delta_R}{\delta_Y}$$
$$\omega = \frac{3.72° - 2.84°}{3.28°} = \frac{0.88}{3.28}$$
$$\boxed{\omega = 0.268 \approx 0.27}$$

Q6. *(NIOS 2016, 2018, 2021 — Standard repeated)*

Calculate the dispersive power for flint glass for the following data: μ_C = 1.6444, μ_D = 1.6520, μ_F = 1.6637 (where C, D & F are Fraunhofer nomenclatures)

Answer: Given: μ_C = 1.6444 (red), μ_F = 1.6637 (violet), μ_D = 1.6520 (yellow/mean)

Dispersive power formula in terms of refractive indices:

$$\omega = \frac{\mu_F - \mu_C}{\mu_D - 1}$$
$$\omega = \frac{1.6637 - 1.6444}{1.6520 - 1} = \frac{0.0193}{0.6520}$$
$$\boxed{\omega = 0.0296 \approx 0.03}$$

Q7. *(NIOS 2015, 2018, 2020 — Almost every year)*

Waves of wavelengths 3934 Å, 5890 Å and 6867 Å are found in the scattered beam when sunlight falls on chimney smoke. Which of these is scattered most intensely? Find the ratio of intensities of scattering for wavelengths 3934 Å and 6867 Å.

Answer: By Rayleigh's Law of Scattering: $I \propto \frac{1}{\lambda^4}$

Since 3934 Å has the **smallest wavelength**, it is scattered **most intensely**.

Ratio of Intensities (I_1 for 3934 Å and I_2 for 6867 Å):

$$\frac{I_1}{I_2} = \frac{\lambda_2^4}{\lambda_1^4} = \left(\frac{6867}{3934}\right)^4$$
$$= \left(\frac{6867}{3934}\right)^4 = (1.745)^4$$
$$= (1.745)^2 \times (1.745)^2 = 3.045 \times 3.045$$
$$\boxed{\frac{I_1}{I_2} \approx 9.27 \approx 9.3}$$

So 3934 Å light is scattered about **9.3 times** more intensely than 6867 Å light.

SECTION C: MY PREDICTED QUESTIONS

Q8. Calculate the refractive index of an equilateral prism if the angle of minimum deviation is equal to the angle of the prism.

Answer: For an equilateral prism: A = 60° Given: δ_m = A = 60°

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)} = \frac{\sin\left(\frac{60^\circ+60^\circ}{2}\right)}{\sin\left(\frac{60^\circ}{2}\right)}$$

$$\mu = \frac{\sin\ 60^\circ}{\sin\ 30^\circ} = \frac{\sqrt{3}/2}{1/2} = \sqrt{3}$$

$$\boxed{\mu = \sqrt{3} \approx 1.732}$$

Q9. A prism of refracting angle 5° is made of glass with μ_V = 1.523 and μ_R = 1.515. Find: (a) angular dispersion, (b) dispersive power.

Answer: Given: A = 5°, μ_V = 1.523, μ_R = 1.515

Mean refractive index: $\mu_Y = (\mu_V + \mu_R)/2$ = (1.523 + 1.515)/2 = 1.519

(a) Deviation for each colour (small-angle prism):

$$\delta_V = (\mu_V - 1) \times A = (1.523 - 1) \times 5^\circ = 0.523 \times 5^\circ = 2.615^\circ$$
$$\delta_R = (\mu_R - 1) \times A = (1.515 - 1) \times 5^\circ = 0.515 \times 5^\circ = 2.575^\circ$$

Angular Dispersion:

$$\delta_V - \delta_R = 2.615^\circ - 2.575^\circ$$
$$\boxed{\text{Angular Dispersion} = 0.040^\circ}$$

(b) Dispersive Power:

$$\omega = \frac{\delta_V - \delta_R}{\delta_Y} = \frac{\mu_V - \mu_R}{\mu_Y - 1} = \frac{1.523 - 1.515}{1.519 - 1} = \frac{0.008}{0.519}$$
$$\boxed{\omega = 0.0154 \approx 0.015}$$

Q10. A light beam has wavelength 4000 Å in vacuum. Find its wavelength and speed in glass of refractive index μ = 1.5. (c = 3 × 10^8 m/s)

Answer: Given: λ_{vacuum} = 4000 Å = 4000 × 10^{-10} m, μ = 1.5

Speed in glass:

$$v = \frac{c}{\mu} = \frac{3 \times 10^8}{1.5}$$
$$\boxed{v = 2 \times 10^8\ \text{m/s}}$$

Wavelength in glass (frequency stays constant):

$$\lambda_{glass} = \frac{\lambda_{vacuum}}{\mu} = \frac{4000}{1.5}$$

$$\boxed{\lambda_{glass} \approx 2667\text{ A} \approx 2.67 \times 10^{-7}\text{ m}}$$

Q11. For a glass prism with A = 60° and μ = 1.5, find the angle of minimum deviation δ_m.

Answer: Given: A = 60°, μ = 1.5

Using:

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

$$1.5 = \frac{\sin\left(\frac{60^\circ+\delta_m}{2}\right)}{\sin\ 30^\circ} = \frac{\sin\left(\frac{60^\circ+\delta_m}{2}\right)}{0.5}$$

$$\sin\left(\frac{60^\circ+\delta_m}{2}\right) = 1.5 \times 0.5 = 0.75$$

$$\frac{60^\circ+\delta_m}{2} = \sin^{-1}(0.75) = 48.59^\circ$$

$$60^\circ + \delta_m = 97.18^\circ$$

$$\boxed{\delta_m = 37.18^\circ \approx 37^\circ}$$

Q12. Compare the intensities of scattering for blue light (λ = 4500 Å) and red light (λ = 7000 Å) in the atmosphere using Rayleigh's law.

Answer: By Rayleigh's Law:

$$\frac{I_{blue}}{I_{red}} = \left(\frac{\lambda_{red}}{\lambda_{blue}}\right)^4 = \left(\frac{7000}{4500}\right)^4$$

$$= \left(\frac{70}{45}\right)^4 = (1.556)^4$$

$$= (1.556)^2 \times (1.556)^2 = 2.421 \times 2.421$$

$$\boxed{\frac{I_{blue}}{I_{red}} \approx 5.86 \approx 6}$$

Conclusion: Blue light is scattered about 6 times more than red light. This is why the sky appears blue and the sun appears red at sunrise/sunset.

12

Wave Phenomena and Light

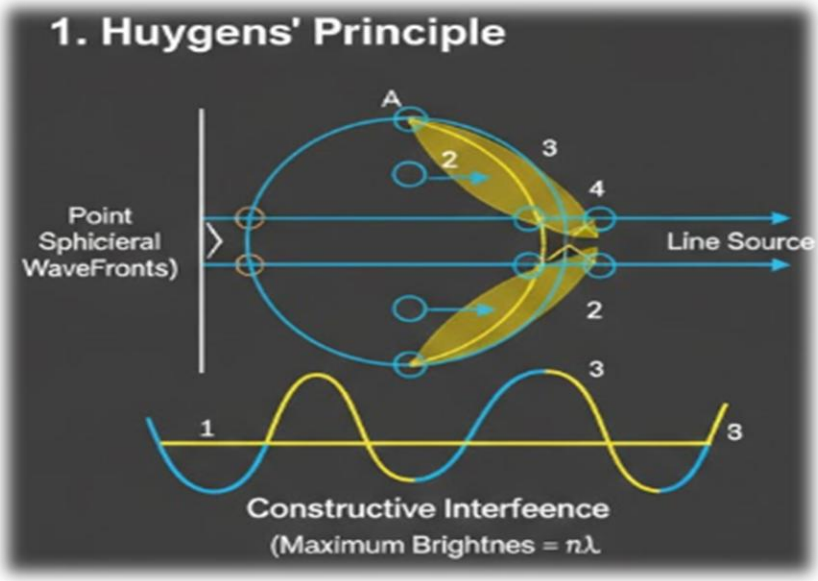
1. Huygens' Principle

Definition: Every point on a given wavefront acts as a source of new disturbance, called secondary wavelets. These wavelets travel in all directions with the speed of light.

The Principle States:

1. Each point on a wavefront is a source of secondary disturbance.
2. The secondary wavelets spread out in all directions with the speed of the wave.
3. A surface touching these secondary wavelets tangentially in the forward direction at any instant gives the new wavefront.

Propagation: This explains how a spherical or plane wavefront moves forward through a medium.



2. Interference of Light

Definition: The phenomenon of redistribution of light energy in a medium due to the superposition of light waves from two **coherent sources**.

Coherent Sources: Sources that emit light waves of the same frequency and have a constant phase difference.

Types of Interference:

1. **Constructive Interference:** When the crest of one wave meets the crest of another. Resultant intensity is maximum. (Path difference $\Delta = n\lambda$).
2. **Destructive Interference:** When the crest of one wave meets the trough of another. Resultant intensity is minimum/zero.. (Path difference $\Delta = (2n+1)\lambda/2$).

3. Diffraction of Light

Definition: The phenomenon of bending of light waves around the edges of an obstacle or aperture and its entry into the geometrical shadow of the obstacle.

Condition for Diffraction: The size of the obstacle/slit must be comparable to the wavelength of light.

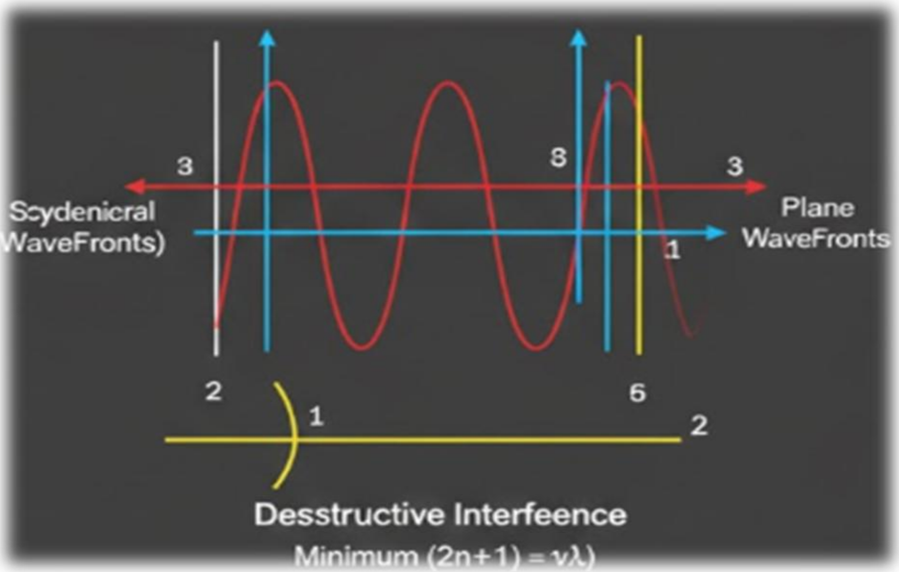
Diffraction by a Single Slit

When monochromatic light passes through a single narrow slit, it forms a central bright fringe surrounded by alternate dark and bright fringes of decreasing intensity.

Central Maximum: Most of the light energy is concentrated here.

Minima Position: $a \sin\theta = n\lambda$ (where a is slit width).

Secondary Maxima Position: $a \sin\theta = (2n+1)\lambda/2$.



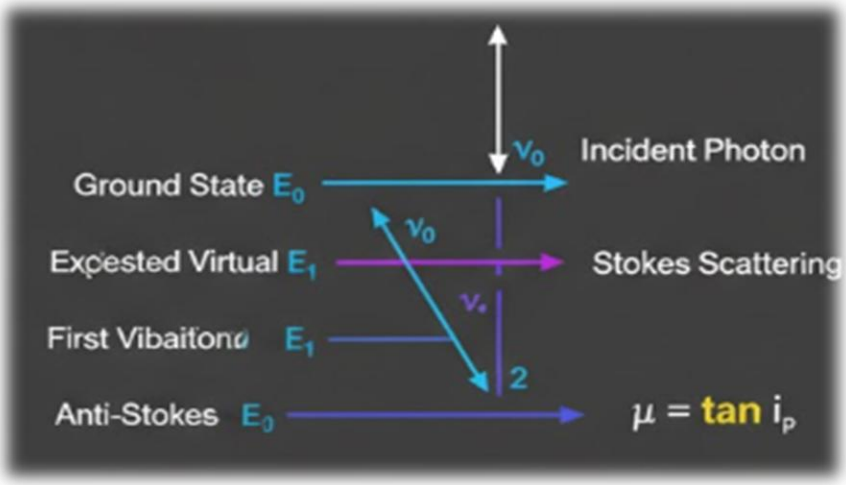
4. Polarization of Light

Definition: The phenomenon of restricting the vibrations of light (electric field vectors) to a single plane perpendicular to the direction of propagation.

Significance: Polarization conclusively proves that light is a **Transverse Wave**. Longitudinal waves (like sound) cannot be polarized.

Unpolarized Light: Vibrations occur in all possible planes.

Plane Polarized Light: Vibrations occur in only one plane.



5. Brewster's Law

Statement: When unpolarized light is incident on a transparent medium at a particular angle (called Brewster's angle $\mathbf{i_p}$), the reflected light is completely plane-polarized.

The Law: The refractive index (μ) of the medium is equal to the tangent of the polarizing angle ($\mathbf{i_p}$)

$$\mu = \tan i_p$$

Derivation:

1. At $i = i_p$, the reflected ray and refracted ray are perpendicular to each other ($r + i_p = 90^\circ$).
2. Using Snell's Law: $\mu = \frac{\sin i_p}{\sin r}$
3. Substitute $r = 90^\circ - i_p$:
   $\mu = \frac{\sin i_p}{\sin(90^\circ - i_p)} = \frac{\sin i_p}{\cos i_p}$
4. Therefore, $\mu = \tan i_p$.

TOP 15 NUMERICAL QUESTIONS & ANSWERS

SECTION A: CHAPTER-BASED NUMERICALS

Q1. In Young's double slit experiment, the slit separation is 2 mm and the distance between slits and screen is 100 cm. Calculate the path difference between waves arriving at a point 5 cm away from the central point on the screen.

Answer: Given: d = 2 mm = 2×10^{-3} m, D = 100 cm = 1 m, x = 5 cm = 5×10^{-2} m

Using the path difference formula:

$$\Delta = \frac{x \cdot d}{D}$$

$$\Delta = \frac{5 \times 10^{-2} \times 2 \times 10^{-3}}{1}$$

$$\Delta = \frac{10 \times 10^{-5}}{1}$$

$$\boxed{\Delta = 10^{-4}\ \text{m} = 0.1\ \text{mm}}$$

Q2. In Young's double slit experiment, the slits are 0.5 mm apart and the screen is 1.5 m away. Find the fringe width if light of wavelength 600 nm is used.

Answer: Given: d = 0.5 mm = 5×10^{-4} m, D = 1.5 m, λ = 600 nm = 600×10^{-9} m

Using fringe width formula:

$$\beta = \frac{\lambda D}{d}$$

$$\beta = \frac{600 \times 10^{-9} \times 1.5}{5 \times 10^{-4}}$$

$$\beta = \frac{900 \times 10^{-9}}{5 \times 10^{-4}} = \frac{9 \times 10^{-7}}{5 \times 10^{-4}}$$

$$\boxed{\beta = 1.8 \times 10^{-3}\ \text{m} = 1.8\ \text{mm}}$$

Q3. In a Young's double slit experiment, the fringe width is found to be 0.4 mm. If the whole apparatus is immersed in water (refractive index = 4/3), find the new fringe width.

Answer: Given: β_{air} = 0.4 mm, μ_{water} = 4/3

When immersed in water, wavelength changes:

$$\lambda_{water} = \frac{\lambda_{air}}{\mu} = \frac{\lambda_{air}}{4/3} = \frac{3\lambda_{air}}{4}$$

Since β = λD/d, fringe width is directly proportional to wavelength:

$$\frac{\beta_{water}}{\beta_{air}} = \frac{\lambda_{water}}{\lambda_{air}} = \frac{3}{4}$$

$$\beta_{water} = \frac{3}{4} \times 0.4\ \text{mm}$$

$$\boxed{\beta_{water} = 0.3 \text{ mm}}$$

Q4. The polarising angle for a medium is 60°. Calculate the refractive index of the medium.

Answer:

Given: i_p = 60°

Using Brewster's Law:

$$\mu = \tan\, i_p$$
$$\mu = \tan\, 60°$$
$$\mu = \sqrt{3}$$
$$\boxed{\mu = \sqrt{3} \approx 1.73}$$

Q5. For a material of refractive index 1.42, calculate the polarising angle for a beam of unpolarised light incident on it.

Answer: Given: μ = 1.42

Using Brewster's Law:

$$\mu = \tan\, i_p$$
$$\tan\, i_p = 1.42$$
$$i_p = \tan^{-1}(1.42)$$
$$\boxed{i_p \approx 54.8° \approx 54°}$$

SECTION B: PREVIOUS YEAR NIOS QUESTIONS

Q6. *(NIOS 2018, 2021, 2023 — Very frequently asked)*

In Young's double slit experiment, two slits are 1 mm apart and the screen is 1 m away. Find: (a) fringe width for λ = 500 nm, (b) position of 3rd bright fringe from centre.

Answer: Given: d = 1 mm = 10^{-3} m, D = 1 m, λ = 500 nm = 5 × 10^{-7} m

(a) Fringe Width:

$$\beta = \frac{\lambda D}{d} = \frac{5 \times 10^{-7} \times 1}{10^{-3}}$$
$$\boxed{\beta = 5 \times 10^{-4} \text{ m} = 0.5 \text{ mm}}$$

(b) Position of 3rd bright fringe (n = 3):

$$x_3 = \frac{n\lambda D}{d} = \frac{3 \times 5 \times 10^{-7} \times 1}{10^{-3}}$$
$$\boxed{x_3 = 1.5 \times 10^{-3} \text{ m} = 1.5 \text{ mm from centre}}$$

Q7. *(NIOS 2017, 2019, 2022 — Standard repeated)*

In Young's double slit experiment, the slit separation is 0.3 mm and the screen is 1.5 m away. If the 4th bright fringe is at 1.6 cm from the central fringe, find the wavelength of light used.

Answer: Given: d = 0.3 mm = 3×10^{-4} m, D = 1.5 m, n = 4, x_4 = 1.6 cm = 1.6×10^{-2} m

Using bright fringe position formula:

$$x_n = \frac{n\lambda D}{d}$$
$$\lambda = \frac{x_n \times d}{n \times D}$$
$$\lambda = \frac{1.6 \times 10^{-2} \times 3 \times 10^{-4}}{4 \times 1.5}$$
$$\lambda = \frac{4.8 \times 10^{-6}}{6}$$
$$\boxed{\lambda = 8 \times 10^{-7}\ \text{m} = 800\ \text{nm}}$$

Q8. *(NIOS 2016, 2019, 2021 — Almost every year)*

In a double slit experiment using light of wavelength 600 nm, the angular width of a fringe on a distant screen is 0.1°. Find the spacing between the slits.

Answer: Given: λ = 600 nm = 600×10^{-9} m, angular fringe width θ = 0.1°

Converting to radians:

$$\theta = 0.1^\circ = 0.1 \times \frac{\pi}{180} = \frac{\pi}{1800} \approx 1.745 \times 10^{-3}\ \text{rad}$$

Angular fringe width:

$$\theta = \frac{\lambda}{d}$$
$$d = \frac{\lambda}{\theta} = \frac{600 \times 10^{-9}}{1.745 \times 10^{-3}}$$
$$\boxed{d = 3.44 \times 10^{-4}\ \text{m} \approx 0.344\ \text{mm}}$$

Q9. *(NIOS 2015, 2018, 2020 — Very frequently asked)*

Light of wavelength 5000 Å is incident on a slit of width 0.1 mm. Find the angular position of the first minimum of the single slit diffraction pattern.

Answer: Given: λ = 5000 Å = 5000×10^{-10} m = 5×10^{-7} m, a = 0.1 mm = 10^{-4} m

For first minimum in single slit diffraction:

$$a\sin\,\theta = \lambda$$
$$\sin\,\theta = \frac{\lambda}{a} = \frac{5 \times 10^{-7}}{10^{-4}} = 5 \times 10^{-3}$$

Since sin θ is very small:

$$\theta \approx 5 \times 10^{-3}\ \text{rad}$$

Converting to degrees:

$$\theta = 5 \times 10^{-3} \times \frac{180}{\pi}$$
$$\boxed{\theta \approx 0.286^\circ \approx 0.29^\circ}$$

Q10. *(NIOS 2016, 2020, 2023 — Repeated consistently)*

In Young's double slit experiment, the distance between the slits is d = 0.25 mm and the screen is D = 100 cm away. If the fringe width is 1.0 mm, find: (a) wavelength of light, (b) position of 5th dark fringe.

Answer:

Given: d = 0.25 mm = 2.5 × 10^{-4} m, D = 1 m, β = 1.0 mm = 10^{-3} m

(a) Wavelength:

$$\beta = \frac{\lambda D}{d} \Rightarrow \lambda = \frac{\beta \times d}{D}$$
$$\lambda = \frac{10^{-3} \times 2.5 \times 10^{-4}}{1}$$
$$\boxed{\lambda = 2.5 \times 10^{-7}\ \text{m} = 250\ \text{nm}}$$

(b) Position of 5th dark fringe (n = 4, since n starts from 0):

$$x_n = \left(n + \frac{1}{2}\right)\frac{\lambda D}{d} = \left(4 + \frac{1}{2}\right) \times \beta$$
$$x_4 = 4.5 \times 1.0\ \text{mm}$$
$$\boxed{x_4 = 4.5\ \text{mm from centre}}$$

SECTION C: PREDICTED QUESTIONS

Q11. Two slits in Young's experiment are 0.2 mm apart. The interference fringes for light of wavelength 6000 Å are formed on a screen 80 cm away. Calculate: (a) fringe width, (b) change in fringe width if screen is moved 20 cm closer.

Answer: Given: d = 0.2 mm = 2 × 10^{-4} m, λ = 6000 Å = 6 × 10^{-7} m

(a) When D = 80 cm = 0.8 m:

$$\beta_1 = \frac{\lambda D_1}{d} = \frac{6 \times 10^{-7} \times 0.8}{2 \times 10^{-4}}$$
$$\boxed{\beta_1 = 2.4 \times 10^{-3}\ \text{m} = 2.4\ \text{mm}}$$

(b) When screen moved 20 cm closer → D_2 = 60 cm = 0.6 m:

$$\beta_2 = \frac{6 \times 10^{-7} \times 0.6}{2 \times 10^{-4}} = 1.8\ \text{mm}$$

Change in fringe width:

$$\Delta\beta = \beta_1 - \beta_2 = 2.4 - 1.8$$
$$\boxed{\Delta\beta = 0.6 \text{ mm (fringe width decreases)}}$$

Q12. In a Young's double slit experiment, the ratio of intensities of bright and dark fringes is 9:1. Find the ratio of amplitudes of the two waves, and ratio of their intensities.

Answer:

Given: $I_{bright} / I_{dark} = 9/1$

Using intensity formulas:

$$\frac{I_{bright}}{I_{dark}} = \frac{(a_1+a_2)^2}{(a_1-a_2)^2} = \frac{9}{1}$$
$$\frac{a_1 + a_2}{a_1 - a_2} = \frac{3}{1}$$

Solving:

$$a_1 + a_2 = 3a_1 - 3a_2$$
$$4a_2 = 2a_1$$
$$\boxed{\frac{a_1}{a_2} = 2:1}$$

Ratio of individual intensities ($I \propto a^2$):

$$\frac{I_1}{I_2} = \frac{a_1^2}{a_2^2} = \frac{4}{1}$$
$$\boxed{I_1 : I_2 = 4:1}$$

Q13. Light of wavelength 500 nm falls on two slits spaced 0.5 mm apart. Find the number of bright fringes between the central maximum and a point 2.5 mm from the centre on the screen, if the screen is 1.2 m away.

Answer:

Given: λ = 500 nm = 5×10^{-7} m, d = 0.5 mm = 5×10^{-4} m, D = 1.2 m, x = 2.5 mm = 2.5×10^{-3} m

Fringe width:

$$\beta = \frac{\lambda D}{d} = \frac{5 \times 10^{-7} \times 1.2}{5 \times 10^{-4}} = 1.2 \times 10^{-3} \text{ m} = 1.2 \text{ mm}$$

Number of fringes:

$$n = \frac{x}{\beta} = \frac{2.5 \text{ mm}}{1.2 \text{ mm}}$$
$$\boxed{n \approx 2.08 \approx 2 \text{ complete bright fringes}}$$

Q14. Light is incident on the surface of glass (μ = 1.5) at the polarising angle. Find: (a) the polarising angle, (b) the angle of refraction.

Answer:

Given: μ = 1.5

(a) Polarising angle (Brewster's Law):

$$\mu = \tan i_p$$
$$\tan i_p = 1.5$$
$$i_p = \tan^{-1}(1.5)$$
$$\boxed{i_p \approx 56.3°}$$

(b) Angle of refraction:

At polarising angle, the reflected and refracted rays are perpendicular:

$$i_p + r = 90°$$
$$r = 90° - i_p = 90° - 56.3°$$
$$\boxed{r \approx 33.7°}$$

Verification using Snell's Law:

$$\mu = \frac{\sin i_p}{\sin r} = \frac{\sin 56.3°}{\sin 33.7°} = \frac{0.832}{0.555} \approx 1.5\checkmark$$

Q15. In Young's double slit experiment, the intensity at the central maximum is I_0. Find the intensity at a point where the path difference is λ/4.

Answer:

Given: Path difference Δ = λ/4, I_0 = intensity at centre

Step 1 — Convert path difference to phase difference:

$$\delta = \frac{2\pi}{\lambda} \times \Delta = \frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \frac{\pi}{2}$$

Step 2 — Use intensity formula:

$$I = 4a^2\cos^2\left(\frac{\delta}{2}\right)$$

At centre (δ = 0): $I_0 = 4a^2 \cos^2(0) = 4a^2$

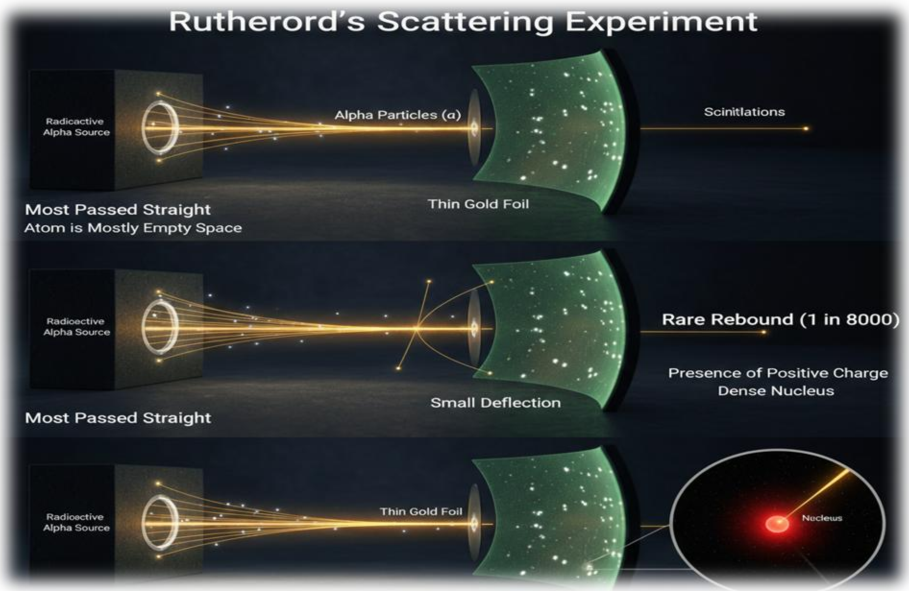
At given point (δ = π/2):

$$I = 4a^2\cos^2\left(\frac{\pi}{4}\right) = 4a^2 \times \left(\frac{1}{\sqrt{2}}\right)^2 = 4a^2 \times \frac{1}{2} = 2a^2$$
$$\frac{I}{I_0} = \frac{2a^2}{4a^2} = \frac{1}{2}$$
$$\boxed{I = \frac{I_0}{2}}$$

13
Structure of Atom

1. Rutherford's Scattering Experiment

The Experiment: Rutherford bombarded a thin gold foil with high-speed alpha particles (**α - particles**) and observed their deflection using a fluorescent screen.



Findings:

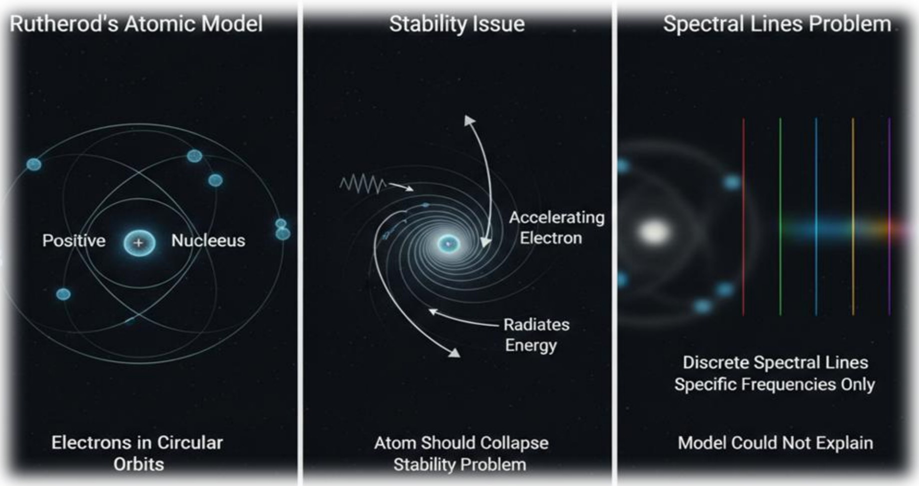
1. **Most α -particles passed straight** through the foil → Most of the atom is empty space.
2. **Some particles were deflected** by small angles → There is a positive charge in the atom.
3. **A few (1 in 8000) rebounded** (**180°** deflection) → The entire positive charge and mass are concentrated in a very small, dense region called the **Nucleus**.

2. Rutherford's Atomic Model & Shortcomings

Model: An atom consists of a tiny, positively charged nucleus at the center, with electrons revolving around it in circular orbits, similar to planets around the sun.

Shortcomings:

1. **Stability Issue:** According to Maxwell's electromagnetic theory, an accelerating electron should radiate energy. If it loses energy, it should spiral into the nucleus, making the atom unstable.



2. **Spectral Lines:** It could not explain why atoms emit light only at specific frequencies (discrete spectra).

3. Bohr's Model of Hydrogen Atom

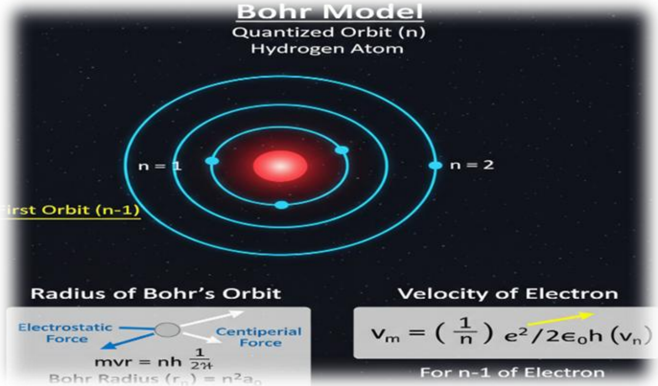
Bohr combined classical mechanics with Planck's quantum theory.

A. Radius of Bohr's Orbit

By balancing electrostatic force and centripetal force $\left(\frac{mv^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2}\right)$ and using Bohr's quantization condition $\left(mvr = \frac{nh}{2\pi}\right)$:

Formula: $r_n = \frac{n^2h^2\epsilon_0}{\pi me^2}$

For the first orbit (n = 1), $r_1 \approx \mathbf{0.53}\ \mathring{A}$ (Bohr radius).



B. Velocity of Electron

Formula: $v_n = \frac{e^2}{2\epsilon_0 nh}$

In the first orbit, the velocity is approximately **1/137** times the speed of light.

4. Energy of an Electron in Hydrogen Atom

The total energy **(E)** is the sum of Kinetic Energy **(K)** and Potential Energy **(U).**

$$K = \frac{1}{2}mv^2 = \frac{e^2}{8\pi\epsilon_0 r}$$

$U = -\frac{e^2}{4\pi\epsilon_0 r}$ (Negative sign indicates attraction)

Total Energy (E_n): $E_n = K + U = -\frac{me^4}{8\epsilon_0^2 n^2 h^2}$

Simplified: **$ E_n = -\frac{13.6}{n^2} , eV $**

5. Energy Level Diagram and Spectrum

When an electron jumps from a higher orbit **(n_2)** to a lower orbit **(n_1)**, it emits a photon of energy **$\Delta E = E_{n2} - E_{n1}$**

Hydrogen Spectral Series:

Lyman Series: n_1 = 1 (Ultraviolet region)

Balmer Series: n_1 = 2 (Visible region)

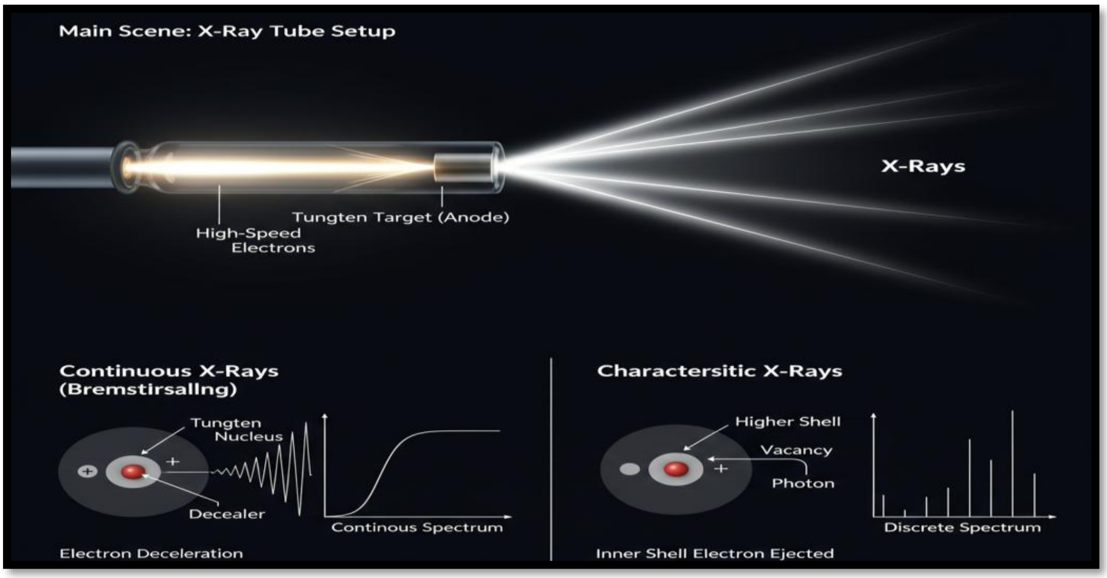
Paschen Series: n_1 = 3 (Infrared region)

Brackett Series: n_1 = 4 (Infrared region)

Pfund Series: n_1 = 5 (Far Infrared region)

6. X-Rays: Production and Laws

Production: X-rays are produced when high-speed electrons are suddenly stopped by a high-melting-point metal target (like Tungsten).



Types:

Continuous X-rays: Produced due to the retardation of electrons (**Bremsstrahlung**).

Characteristic X-rays: Produced when an incident electron knocks out an inner-shell electron of the target atom.

Important Laws:

Duane-Hunt Law: The minimum wavelength (λ_{min}) of X-rays depends on the accelerating voltage (V).

- $\lambda_{min} = \frac{hc}{eV} \approx \frac{12400}{V}$ Å

Moseley's Law: The frequency (f) of characteristic X-rays is related to the atomic number (Z) of the target.

- $\sqrt{f} = a(Z - b)$ (Proves that Z, not atomic weight, is the fundamental property).

TOP 12 NUMERICAL QUESTIONS & ANSWERS

SECTION A: CHAPTER-BASED NUMERICALS

Q1. Calculate the radius of the 3rd and 4th permitted orbits of electron in the hydrogen atom. Given a_0 = 0.53 Å (Bohr radius).

Answer: Using the formula: $r_n = n^2 \times a_0$

Radius of 3rd orbit (n = 3):

$$r_3 = (3)^2 \times 0.53\ \text{A} = 9 \times 0.53$$
$$\boxed{r_3 = 4.77\ A}$$

Radius of 4th orbit (n = 4):

$$r_4 = (4)^2 \times 0.53\ \text{A} = 16 \times 0.53$$
$$\boxed{r_4 = 8.48\ A}$$

Note: Ratio of radii $r_1 : r_2 : r_3 : r_4$ = 1 : 4 : 9 : 16

Q2. The energy transition in H-atom occurs from n = 3 to n = 2 energy level. Given R = 1.097 × 10^7 m^{-1}. Find: (a) wavelength of emitted radiation, (b) spectral series it belongs to.

Answer: Given: n_1 = 2 (lower), n_2 = 3 (higher), R = 1.097 × 10^7 m^{-1}

Using Balmer series formula:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right) = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$
$$\frac{1}{\lambda} = 1.097 \times 10^7\left(\frac{1}{4} - \frac{1}{9}\right) = 1.097 \times 10^7 \times \frac{9-4}{36}$$
$$\frac{1}{\lambda} = 1.097 \times 10^7 \times \frac{5}{36} = 1.097 \times 10^7 \times 0.1389$$
$$\frac{1}{\lambda} = 1.524 \times 10^6\ \text{m}^{-1}$$
$$\lambda = \frac{1}{1.524 \times 10^6}$$
$$\boxed{\lambda = 6.56 \times 10^{-7}\ \text{m} = 6563\ A}$$

(b) Series: This transition (n=3 → n=2) belongs to **Balmer Series** (visible region).

Q3. The ionisation potential of hydrogen is 13.6 V. Find the energy of the hydrogen atom in: (a) ground state (n=1), (b) n = 2 state, (c) n = 3 state.

Answer: Using energy formula: $E_n = \frac{-13.6}{n^2}$ eV

(a) Ground state (n = 1): $E_1 = \frac{-13.6}{1^2}$

$$\boxed{E_1 = -13.6\ \text{eV}}$$

(b) n = 2 state: $E_2 = \frac{-13.6}{4}$

$$\boxed{E_2 = -3.4 \text{ eV}}$$

(c) n = 3 state: $E_3 = \frac{-13.6}{9}$

$$\boxed{E_3 = -1.51 \text{ eV}}$$

Note: Negative sign means electron is **bound** to the nucleus. Energy required to ionise from n=1 = +13.6 eV.

Q4. An electron in a hydrogen atom jumps from n = 3 to n = 1. Calculate: (a) energy of emitted photon, (b) frequency of emitted radiation. (h = 6.62 × 10^{-34} Js, 1 eV = 1.6 × 10^{-19} J)

Answer: Given: n_i = 3, n_f = 1

Energy of emitted photon:

$$\Delta E = E_3 - E_1 = \left(\frac{-13.6}{9}\right) - \left(\frac{-13.6}{1}\right)$$
$$\Delta E = -1.51 - (-13.6) = 13.6 - 1.51$$
$$\Delta E = 12.09 \text{ eV}$$

Converting to Joules: $\Delta E = 12.09 \times 1.6 \times 10^{-19}$

$$\boxed{\Delta E = 1.934 \times 10^{-18} \text{ J}}$$

Frequency: $\nu = \frac{\Delta E}{h} = \frac{1.934\times10^{-18}}{6.62\times10^{-34}}$

$$\boxed{\nu \approx 2.92 \times 10^{15} \text{ Hz}}$$

(This belongs to Lyman Series — UV region)

SECTION B: PREVIOUS YEAR NIOS QUESTIONS

Q5. *(NIOS 2019, 2022, 2023 — Very frequently asked)*

What is the ratio of energies of hydrogen atom in its first excited state (n=2) to that in its second excited state (n=3)?

Answer: Given: First excited state n = 2, Second excited state n = 3

$$E_n = \frac{-13.6}{n^2} \text{ eV}$$
$$E_2 = \frac{-13.6}{4} = -3.4 \text{ eV}$$
$$E_3 = \frac{-13.6}{9} = -1.51 \text{ eV}$$

Ratio: $\frac{E_2}{E_3} = \frac{-3.4}{-1.51} = \frac{-13.6/4}{-13.6/9} = \frac{9}{4}$

Q6. *(NIOS 2017, 2020, 2022 — Standard repeated)*

The Rydberg constant for hydrogen is R = 1.097 × 10^7 m^{-1}. Calculate the short wavelength limit (series limit) and long wavelength limit of Lyman series.

Answer: Given: R = 1.097×10^7 m^{-1}

Lyman Series: transitions to $n_1 = 1$

Short wavelength limit (series limit): $n_2 \to \infty$

$$\frac{1}{\lambda_{min}} = R\left(\frac{1}{1^2} - \frac{1}{\infty^2}\right) = R \times 1$$

$$\lambda_{min} = \frac{1}{R} = \frac{1}{1.097 \times 10^7}$$

$$\boxed{\lambda_{min} = 9.116 \times 10^{-8} \text{ m} = 911.6\ \AA}$$

Long wavelength limit (first line): $n_2 = 2$

$$\frac{1}{\lambda_{max}} = R\left(\frac{1}{1^2} - \frac{1}{2^2}\right) = R\left(1 - \frac{1}{4}\right) = \frac{3R}{4}$$

$$\lambda_{max} = \frac{4}{3R} = \frac{4}{3 \times 1.097 \times 10^7}$$

$$\boxed{\lambda_{max} = 1.215 \times 10^{-7} \text{ m} = 1215\ \AA}$$

Q7. *(NIOS 2016, 2018, 2021 — Repeated every few years)*

An electron in hydrogen atom jumps from n = 4 to n = 2. Find the number of spectral lines that can be emitted. Also find the wavelength of the first line of the Balmer series. (R = 1.097 × 10^7 m^{-1})

Answer: **Number of spectral lines** when electron jumps from n = 4:

$$\text{Number of lines} = \frac{n(n-1)}{2} = \frac{4 \times 3}{2}$$

$$\boxed{\text{Number of spectral lines} = 6}$$

Wavelength of first line of Balmer series (n=3 → n=2):

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{3^2}\right) = 1.097 \times 10^7 \times \frac{5}{36}$$

$$\frac{1}{\lambda} = 1.524 \times 10^6 \text{ m}^{-1}$$

$$\boxed{\lambda = 6563 \text{ A} \approx 656.3 \text{ nm}}$$

Q8. *(NIOS 2015, 2018, 2020, 2023 — Almost every year)*

Using Duane-Hunt Law, find the minimum wavelength of X-rays produced when electrons are accelerated through a potential difference of 30 kV. (h = 6.62 × 10^{-34} Js, c = 3 × 10^8 m/s, e = 1.6 × 10^{-19} C)

Answer: Given: V = 30 kV = 30,000 V

Using Duane-Hunt Law:

$$eV = \frac{hc}{\lambda_{min}}$$

$$\lambda_{min} = \frac{hc}{eV}$$

$$\lambda_{min} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 30000}$$

$$\lambda_{min} = \frac{19.86 \times 10^{-26}}{4.8 \times 10^{-15}}$$

$$\lambda_{min} = \frac{19.86}{4.8} \times 10^{-11}$$

$$\boxed{\lambda_{min} = 4.14 \times 10^{-11}\ \text{m} = 0.414\ A}$$

SECTION C: MY PREDICTED QUESTIONS

Q9. An electron jumps from third orbit to first orbit in hydrogen atom. Calculate the change in angular momentum of the electron. (h = 6.62 × 10^{-34} Js)

Answer: By Bohr's quantisation condition: $L_n = \frac{nh}{2\pi}$

Angular momentum in orbit 3: $L_3 = \frac{3h}{2\pi}$

Angular momentum in orbit 1: $L_1 = \frac{1 \times h}{2\pi}$

Change in angular momentum:

$$\Delta L = L_3 - L_1 = \frac{3h}{2\pi} - \frac{h}{2\pi} = \frac{2h}{2\pi} = \frac{h}{\pi}$$

$$\Delta L = \frac{6.62 \times 10^{-34}}{\pi} = \frac{6.62 \times 10^{-34}}{3.14}$$

$\boxed{\Delta L = 2.11 \times 10^{-34}}$ J\cdotps

Q10. Calculate the frequency of revolution of the electron in the first orbit of hydrogen atom. Given: v_1 = 2.18 × 10^6 m/s, r_1 = 0.53 Å = 0.53 × 10^{-10} m.

Answer: Given: v_1 = 2.18 × 10^6 m/s, r_1 = 0.53 × 10^{-10} m

Circumference of first orbit: $C = 2\pi r_1 = 2 \times 3.14 \times 0.53 \times 10^{-10} = 3.33 \times 10^{-10}$ m

Frequency of revolution:

$$f = \frac{v_1}{2\pi r_1} = \frac{2.18 \times 10^{6}}{3.33 \times 10^{-10}}$$

$$\boxed{f = 6.54 \times 10^{15}\ \text{Hz} \approx 6.57 \times 10^{15}\ \text{Hz}}$$

(Electron goes around the first orbit about 6.57 × 10^{15} times per second!)

Q11. In a hydrogen atom, find the energy of photon emitted when electron transitions occur: (a) n=4 → n=2, (b) n=5 → n=3. (1 eV = 1.6 × 10^{-19} J)

Answer: Using: $E_n = \frac{-13.6}{n^2}$eV

(a) n = 4 → n = 2:

$$\Delta E = E_2 - E_4 = \left(\frac{-13.6}{4}\right) - \left(\frac{-13.6}{16}\right)$$
$$= -3.4 - (-0.85) = -3.4 + 0.85$$
$\boxed{\Delta E = 2.55\ \text{eV}}$(Balmer series — visible)

(b) n = 5 → n = 3:

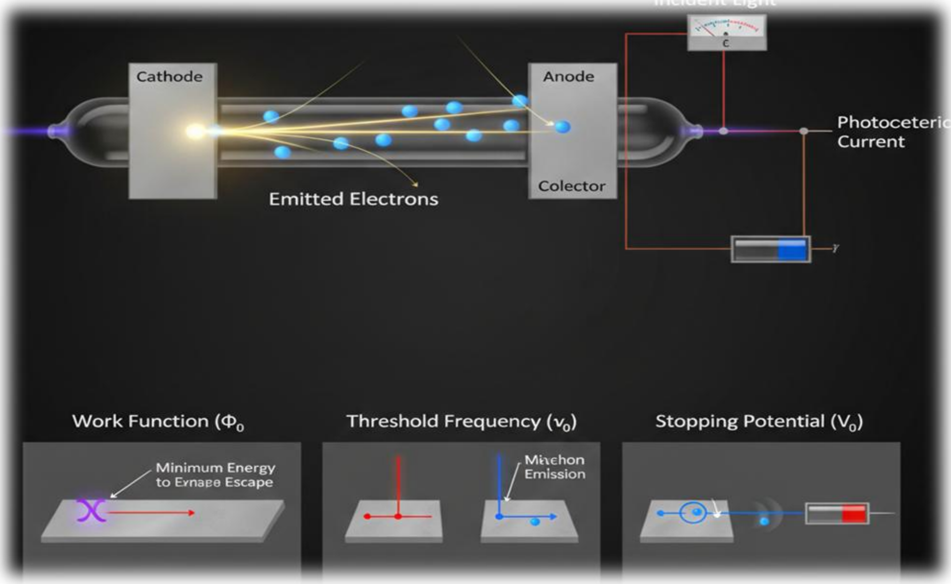
$$\Delta E = E_3 - E_5 = \left(\frac{-13.6}{9}\right) - \left(\frac{-13.6}{25}\right)$$
$$= -1.511 - (-0.544) = -1.511 + 0.544$$
$\boxed{\Delta E = 0.967\ \text{eV}}$(Paschen series — infrared)

14

Dual Nature of Radiation and Matter

1. Photoelectric Effect

Definition: The phenomenon of emission of electrons from a metal surface when light of a sufficiently high frequency (ultraviolet or even visible for some metals) falls on it.



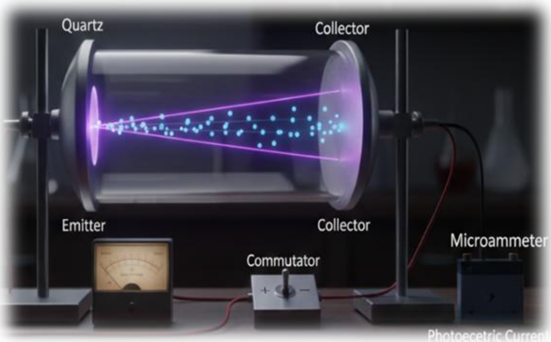
Key Terms:

1. **Work Function (Φ0):** The minimum energy required by an electron to just escape from the metal surface.
2. **Threshold Frequency (ν_0):** The minimum frequency of incident radiation below which no photoelectrons are emitted.
3. **Stopping Potential (V_0):** The negative (**retarding**) potential applied to the collector plate at which the photoelectric current becomes zero.

2. Experimental Arrangement to Study Photoelectric Effect

The setup consists of an evacuated glass/quartz tube containing two electrodes: a photosensitive plate (**Emitter**) and a collector plate.

Monochromatic light enters through a quartz window and falls on the emitter.



The photoelectrons are attracted to the collector, creating a current measured by a microammeter.

A commutator allows us to change the potential difference and its polarity between the plates.

3. Laws of Photoelectric Emission

Based on experimental observations, the following laws were established:

Instantaneous Process: There is no time lag between the incidence of light and the emission of electrons.

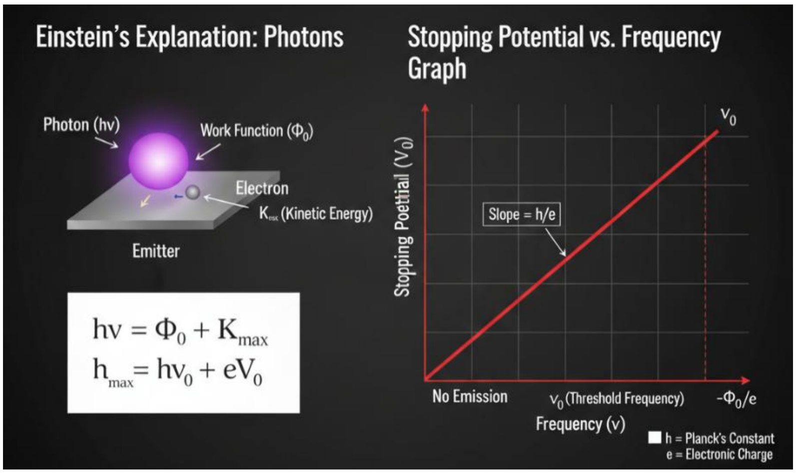
Threshold Frequency: For every metal, there is a minimum frequency (ν_0) below which emission is impossible, regardless of intensity.

Intensity vs. Current: The number of photoelectrons emitted (current) is directly proportional to the **intensity** of incident light.

Kinetic Energy vs. Frequency: The maximum kinetic energy of photoelectrons depends on the **frequency** of light, not on its intensity.

4. Einstein's Photoelectric Equation & Graph Analysis

Einstein explained this effect by treating light as particles called **photons**.



Equation: $h\nu = \Phi_0 + K_{max}$ OR $h\nu = h\nu_0 + eV_0$

Graph (Stopping Potential V_0 vs. Frequency ν):

The graph is a straight line.

The **x-intercept** gives the threshold frequency (**ν_0**).

The **slope** of the graph is equal to h/e (Planck's constant/electronic charge).

The **y-intercept** (when extrapolated) represents **$-\Phi_0$-/e**

5. de Broglie Wavelength of Matter Waves

Louis de Broglie proposed that if radiation has a dual nature, matter must also exhibit wave-like properties.

Matter Waves: Waves associated with moving particles.

de Broglie Equation:

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

Where h is Planck's constant (**6.63 x 10^{-34} Js**) and **p** is momentum.

In terms of Kinetic Energy (K): $\lambda = \frac{h}{\sqrt{2mK}}$

For an Electron accelerated by Voltage (V):

$$\lambda = \frac{12.27}{\sqrt{V}} \text{ Å}$$

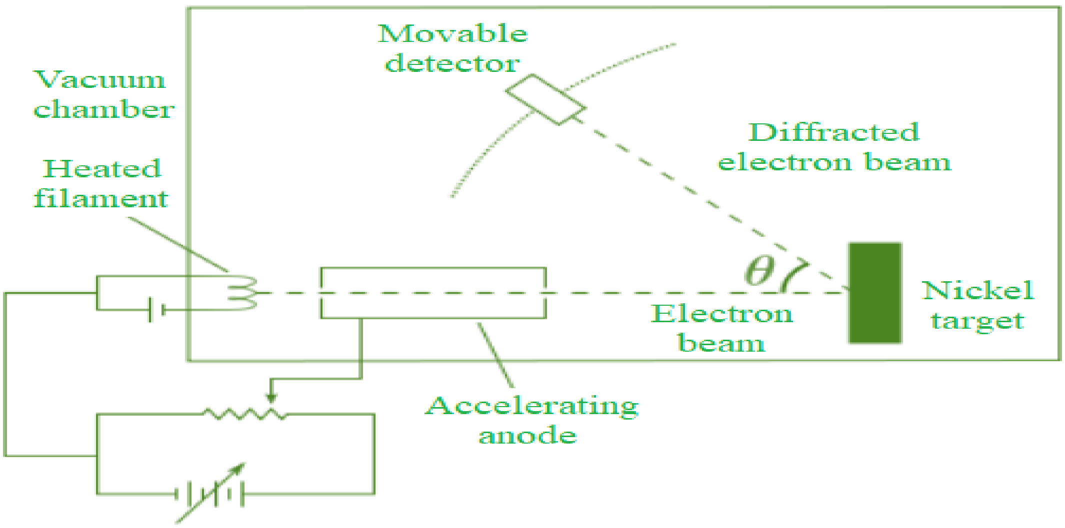
6. Davisson-Germer Experiment

This experiment provided the first experimental verification of the wave nature of electrons.

Setup: A fine beam of electrons is accelerated and fired at a Nickel crystal.

Observation: The scattered electrons showed a diffraction pattern (**interference**) at a specific angle **(54°)** and voltage **(54V).**

Conclusion: Since diffraction is a wave property, electrons must have a wave nature.



Davisson Germer Experiment

TOP NUMERICAL QUESTIONS

SECTION A — 5 MOST IMPORTANT QUESTIONS FROM THE CHAPTER

Q1. Sodium has a work function of 2.3 eV. Light of wavelength 5 × 10^{-7} m is incident on it. Calculate: (i) The threshold frequency (ii) The maximum velocity of emitted photoelectrons (iii) The stopping potential

Given: h = 6.6 × 10^{-34} J s, c = 3 × 10^{8} m/s, m = 9.1 × 10^{-31} kg, 1 eV = 1.6 × 10^{-19} J

Solution:

(i) Threshold Frequency:

$$\phi_0 = h\nu_0 \implies \nu_0 = \frac{\phi_0}{h}$$
$$\nu_0 = \frac{2.3 \times 1.6 \times 10^{-19}}{6.6 \times 10^{-34}} = \frac{3.68 \times 10^{-19}}{6.6 \times 10^{-34}}$$
$$\boxed{\nu_0 = 5.6 \times 10^{14} \text{ Hz}}$$

(ii) Maximum Velocity:

Energy of photon: $E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{5\times10^{-7}} = 3.96 \times 10^{-19}\text{J}$

Using Einstein's equation: $E = \phi_0 + \frac{1}{2}mv_{max}^2$

$$\frac{1}{2}mv_{max}^2 = 3.96 \times 10^{-19} - 3.68 \times 10^{-19} = 0.28 \times 10^{-19} \text{ J}$$
$$v_{max} = \sqrt{\frac{2 \times 0.28 \times 10^{-19}}{9.1 \times 10^{-31}}} = \sqrt{\frac{0.56 \times 10^{-19}}{9.1 \times 10^{-31}}}$$
$$\boxed{v_{max} = 2.5 \times 10^{5} \text{ m/s}}$$

(iii) Stopping Potential:

$$eV_0 = \frac{1}{2}mv_{max}^2 = 0.28 \times 10^{-19} \text{ J}$$
$$V_0 = \frac{0.28 \times 10^{-19}}{1.6 \times 10^{-19}} = \boxed{0.18 \text{ V}}$$

Q2. Calculate the maximum kinetic energy of photoelectrons emitted from a zinc plate when light of frequency ν = 10^{15} Hz is incident on it. Work function of zinc = 3.4 eV.

Given: h = 6.625 × 10^{-34} J s

Solution: Using Einstein's equation: $K_{max} = h\nu - \phi_0$

$$E = h\nu = 6.625 \times 10^{-34} \times 10^{15} = 6.625 \times 10^{-19} \text{ J}$$
$$\phi_0 = 3.4 \times 1.602 \times 10^{-19} = 5.447 \times 10^{-19} \text{ J}$$
$$K_{max} = (6.625 - 5.447) \times 10^{-19}$$
$$\boxed{K_{max} = 1.178 \times 10^{-19} \text{ J} \approx 0.736 \text{ eV}}$$

Q3. A 50 g ball rolls along a table with a speed of 20 cm/s. Calculate its de Broglie wavelength.

Given: h = 6.625 × 10^{-34} J s

Solution:

$$p = mv = 0.050 \text{ kg} \times 0.20 \text{ m/s} = 0.01 \text{ kg m/s}$$
$$\lambda = \frac{h}{p} = \frac{6.625 \times 10^{-34}}{0.01}$$
$$\boxed{\lambda = 6.625 \times 10^{-32} \text{ m}}$$

SECTION B — 5 QUESTIONS FROM PREVIOUS YEAR NIOS / BOARD PAPERS (REPEATED PATTERN)

Q4. ***(NIOS / Board PYQ — Repeated Pattern 2021, 2022, 2023)***

The work function of caesium is 2.14 eV. Find: (a) The threshold frequency for caesium (b) The stopping potential when light of frequency 8 × 10^{14} Hz is incident on it

Given: h = 6.63 × 10^{-34} J s, e = 1.6 × 10^{-19} C

Solution:

(a)

$$\nu_0 = \frac{\phi_0}{h} = \frac{2.14 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = \frac{3.424 \times 10^{-19}}{6.63 \times 10^{-34}}$$
$$\boxed{\nu_0 = 5.16 \times 10^{14} \text{ Hz}}$$

(b)Using: $eV_0 = h(\nu - \nu_0)$

$$V_0 = \frac{h(\nu - \nu_0)}{e} = \frac{6.63 \times 10^{-34} \times (8 - 5.16) \times 10^{14}}{1.6 \times 10^{-19}}$$
$$= \frac{6.63 \times 10^{-34} \times 2.84 \times 10^{14}}{1.6 \times 10^{-19}} = \frac{1.883 \times 10^{-19}}{1.6 \times 10^{-19}}$$
$$\boxed{V_0 = 1.177 \text{ V} \approx 1.18 \text{ V}}$$

Q5. ***(Board PYQ — Repeated 2019, 2021, 2023)***

Light of wavelength 2000 Å falls on a metal surface of work function 4.2 eV. (a) What is the kinetic energy (in eV) of the fastest electrons emitted? (b) What is the stopping potential?

Given: h = 6.63 × 10^{-34} J s, c = 3 × 10^{8} m/s, 1 eV = 1.6 × 10^{-19} J

Solution:

(a)

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{2000 \times 10^{-10}} = \frac{1.989 \times 10^{-25}}{2 \times 10^{-7}} = 9.945 \times 10^{-19} \text{ J}$$
$$E = \frac{9.945 \times 10^{-19}}{1.6 \times 10^{-19}} = 6.22 \text{ eV}$$
$$K_{max} = E - \phi_0 = 6.22 - 4.2 = \boxed{2.02 \text{ eV}}$$

(b) Since $eV_0 = K_{max}$: $\boxed{V_0 = 2.02 \text{ V}}$

Q6. ***(Board PYQ — Repeated Pattern 2019, 2021, 2022, 2023)***

When light of wavelength 500 nm is incident on a metal surface, the stopping potential is found to be 0.65 V. Find: (a) The kinetic energy of the fastest photoelectrons (b) The work function of the metal (c) The threshold frequency

Given: h = 6.63 × 10^{-34} J s, c = 3 × 10^{8} m/s, e = 1.6 × 10^{-19} C

Solution:

(a)

$$K_{max} = eV_0 = 1.6 \times 10^{-19} \times 0.65 = 1.04 \times 10^{-19} \text{ J} = \boxed{0.65 \text{ eV}}$$

(b)

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{500 \times 10^{-9}} = 3.978 \times 10^{-19} \text{ J} = 2.49 \text{ eV}$$
$$\phi_0 = E - K_{max} = 2.49 - 0.65 = \boxed{1.84 \text{ eV}}$$

(c)

$$\nu_0 = \frac{\phi_0}{h} = \frac{1.84 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = \frac{2.944 \times 10^{-19}}{6.63 \times 10^{-34}}$$
$$\boxed{\nu_0 = 4.44 \times 10^{14} \text{ Hz}}$$

Q7. ***(Board PYQ — Repeated 2022, 2023, 2024)*** **The threshold frequency of a metal is 5 × 10^{14} Hz. A photon of wavelength 6000 Å is incident on it. Determine whether the photoelectric effect will occur or not. Justify your answer with calculation.**

Given: h = 6.63 × 10^{-34} J s, c = 3 × 10^{8} m/s

Solution:

Frequency of incident photon:

$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^{8}}{6000 \times 10^{-10}} = \frac{3 \times 10^{8}}{6 \times 10^{-7}} = 5 \times 10^{14} \text{ Hz}$$

Since $\nu = \nu_0 = 5 \times 10^{14}$Hz, the incident frequency exactly equals the threshold frequency.

$\boxed{\text{The photoelectric effect will just barely occur, but } K_{max} = 0. \text{ No energetic photoelectron is emitted.}}$

(Photoemission happens at the threshold, but electrons are emitted with zero kinetic energy.)

SECTION C — 5 PREDICTED HIGH-PROBABILITY QUESTIONS (Will 100% Appear in Exam)

Q8. ***(Predicted — Definitely Coming)***

A photon has a wavelength of 4000 Å. Calculate: (i) Its energy in joules and in eV (ii) Its momentum

Given: h = 6.63 × 10^{-34} J s, c = 3 × 10^8 m/s, 1 eV = 1.6 × 10^{-19} J

Solution:

(i) Energy:

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{4000 \times 10^{-10}} = \frac{1.989 \times 10^{-25}}{4 \times 10^{-7}}$$
$$\boxed{E = 4.97 \times 10^{-19}\ \text{J} = 3.11\ \text{eV}}$$

(ii) Momentum:

$$p = \frac{h}{\lambda} = \frac{E}{c} = \frac{6.63 \times 10^{-34}}{4 \times 10^{-7}}$$
$$\boxed{p = 1.66 \times 10^{-27}\ \text{kg m/s}}$$

Q9. ***(Predicted — Definitely Coming)***

The photoelectric cut-off voltage (stopping potential) in a certain experiment is 1.5 V. What is the maximum kinetic energy of the photoelectrons emitted?

Given: e = 1.6 × 10^{-19} C

Solution:

$$K_{max} = eV_0 = 1.6 \times 10^{-19} \times 1.5$$
$$\boxed{K_{max} = 2.4 \times 10^{-19}\ \text{J} = 1.5\ \text{eV}}$$

(Direct formula application — always asked for 2 marks)

Q10. ***(Predicted — Very High Probability)***

Iron has a work function of 4.8 eV. Calculate: (i) Its threshold frequency (ii) Whether light of wavelength 2500 Å can cause photoelectric emission or not

Given: h = 6.63 × 10^{-34} J s, c = 3 × 10^8 m/s, 1 eV = 1.6 × 10^{-19} J

Solution:

(i)

$$\nu_0 = \frac{\phi_0}{h} = \frac{4.8 \times 1.6 \times 10^{-19}}{6.63 \times 10^{-34}} = \frac{7.68 \times 10^{-19}}{6.63 \times 10^{-34}}$$
$$\boxed{\nu_0 = 1.158 \times 10^{15}\ \text{Hz}}$$

(ii) Frequency of incident light:

$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{2500 \times 10^{-10}} = 1.2 \times 10^{15}\ \text{Hz}$$

Since $\nu = 1.2 \times 10^{15} > \nu_0 = 1.158 \times 10^{15}$Hz,

$$\boxed{\text{Yes, photoelectric emission WILL occur.}}$$

$$K_{max} = h(\nu - \nu_0) = 6.63 \times 10^{-34} \times (1.2 - 1.158) \times 10^{15} = 6.63 \times 10^{-34} \times 0.042 \times 10^{15}$$
$$= 0.028 \times 10^{-19}\ \text{J} = 0.175\ \text{eV}$$

Q11. ***(Predicted — Will Definitely Come)***

If the wavelength of electromagnetic radiation is doubled, what happens to the energy of photons? If a proton and an electron have the same de Broglie wavelength, find the ratio of their momenta and kinetic energies.

Solution:

Part 1 — Effect of doubling wavelength:

$$E = \frac{hc}{\lambda}$$

If $\lambda \to 2\lambda$, then:

$$E' = \frac{hc}{2\lambda} = \frac{E}{2}$$
$$\boxed{\text{Energy becomes HALF when wavelength is doubled.}}$$

Part 2 — Equal de Broglie wavelength:

Since $\lambda = h/p$, for same λ:

$$p_{proton} = p_{electron} \implies \frac{p_p}{p_e} = \boxed{1:1}$$

For kinetic energies (KE = $p^2/2m$):

$$\frac{KE_p}{KE_e} = \frac{p^2/2m_p}{p^2/2m_e} = \frac{m_e}{m_p} = \frac{9.1 \times 10^{-31}}{1.67 \times 10^{-27}}$$
$$\boxed{\frac{KE_p}{KE_e} = \frac{1}{1836}}$$

The proton has much less kinetic energy than the electron for the same de Broglie wavelength.

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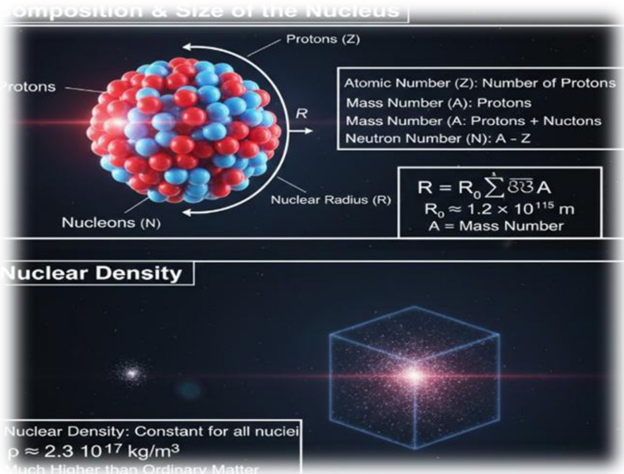
Nuclei and Radioactivity

1. Composition and Size of the Nucleus



Nucleons: The protons and neutrons present inside the nucleus.

Atomic Number (Z): Number of protons.

Mass Number (A): Total number of protons + neutrons.

Neutron Number (N): A - Z

Nuclear Size: Experimental results show that the volume of a nucleus is proportional to its mass number. The radius R is given by:

$$R = R_0 A^{1/3}$$

Where $R_0 \approx 1.2 \times 10^{-15}\, m$ (or $1.2\, fm$).

Nuclear Density: It is constant for all nuclei and is approximately **2.3 x 1017**, which is much higher than ordinary matter.

2. Nuclear Forces

The force that holds protons and neutrons together in the tiny nucleus despite the strong electrostatic repulsion between protons.

Properties:

Strongest Force: It is the strongest known force in nature.

Short-Range: It acts only over distances of a few femtometers (**10^{-15}m**).

Charge Independent: The force between **p-p, n-n**, and **p-n** is the same.

Saturation: A nucleon interacts only with its immediate neighbors.

3. Mass Defect and Binding Energy

Mass Defect (Δ m): The difference between the sum of the masses of individual nucleons and the actual mass of the nucleus.

$$\Delta m = [Zm_p + (A - Z)m_n] - M_{nucleus}$$

Binding Energy (B.E.): The energy equivalent of the mass defect **(using E = Δ mc²).** It is the energy required to break the nucleus into its individual nucleons.

$$1\, amu = 931\, MeV.$$

4. Binding Energy per Nucleon (B.E./A) Curve

This curve is the best indicator of nuclear stability.

Observations:

Intermediate Nuclei (30 < A < 170): Have high and constant **B.E./A** $(\approx 8\, MeV)$. These are the most stable. **Iron (^{56}Fe)** is the most stable.

Light Nuclei (A < 30): Have lower **B.E./A.** They tend to undergo **Nuclear Fission** (if heavy) or **Nuclear Fusion** (if light) to gain stability.

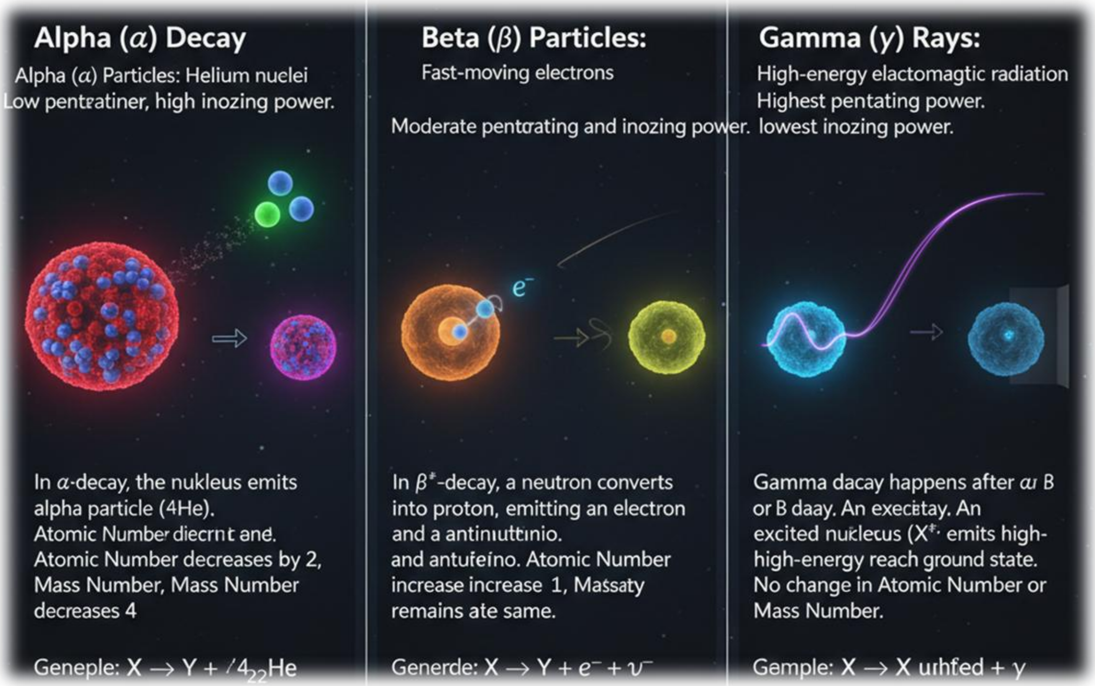
Heavy Nuclei (A > 170): **B.E./A** drops, making them unstable and radioactive.

5. Radioactivity

Definition: The spontaneous disintegration of an unstable nucleus with the emission of radiations.

Types of Radiations:

Alpha (α) Particles: Helium nuclei $({}^4_2He)$ Low penetrating power, high ionizing power.



In **α** - decay, the nucleus emits an alpha particle, which is a Helium nucleus $({}^4_2He)$ As a result, the **Atomic Number decreases by 2** and the **Mass Number decreases by 4**

General Reaction:

$$ {}^A_ZX \longrightarrow {}^{A-4}_{Z-2}Y + {}^4_2He(\alpha) $$

Example (Decay of Uranium-238):

$$ {}^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^4_2He $$

Beta (β) Particles: Fast-moving electrons. Moderate penetrating and ionizing power.

In **β** - decay (specifically **β**$^-$), a neutron inside the nucleus converts into a proton and emits an electron (beta particle) and an antineutrino. The **Atomic Number increases by 1**, but the **Mass Number remains the same**.

General Reaction:

$$ {}^A_ZX \longrightarrow {}^A_{Z+1}Y + {}^0_{-1}e(\beta^-) + \bar{\nu} $$

Example (Decay of Phosphorus-32):

$$ {}^{32}_{15}P \longrightarrow {}^{32}_{16}S + {}^0_{-1}e + \bar{\nu} $$

Here, Phosphorus changes into Sulfur

Gamma (γ) Rays: High-energy electromagnetic radiation. Highest penetrating power, lowest ionizing power.

Gamma decay usually happens after **α** or **β** decay if the daughter nucleus is left in an **excited state** (**X**). It emits a high-energy photon (Gamma ray) to return to the ground state. There is **no change** in Atomic Number or Mass Number.

General Reaction:

$$ {}^A_ZX^* \longrightarrow {}^A_ZX + \gamma $$

Example (Excited Cobalt-60):

$$ {}^{60}_{27}Co^* \longrightarrow {}^{60}_{27}Co + \gamma $$

6. Radioactive Decay Law

The number of nuclei decaying per unit time is proportional to the number of nuclei present at that time.

$$\frac{dN}{dt} = -\lambda N \implies N = N_0 e^{-\lambda t}$$

Decay Constant (λ): The probability of decay per unit time.

Half-Life ($T_{1/2}$): The time taken for half the radioactive nuclei to decay.

$$T_{1/2} = \frac{0.693}{\lambda}$$

Mean Life (T): The average lifetime of a radioactive nucleus. $\tau = 1/\lambda$.

7. Uses of Radioactivity

Medical: **Cobalt-60** for cancer treatment; Iodine-**131** for thyroid study.

Agriculture: To study plant growth and preserve food.

Industry: To detect leaks in underground pipes and thickness control.

Carbon Dating: Using **C-14** to determine the age of fossils.

TOP NUMERICAL QUESTIONS — NUCLEI AND RADIOACTIVITY

SECTION A — 5 MOST IMPORTANT QUESTIONS FROM THE CHAPTER

Q1. Calculate the number of electrons, protons, neutrons and nucleons in an atom of $^{238}_{92}U$.

Solution:

Atomic Number $Z = 92$ = Number of Protons = Number of Electrons
Mass Number $A = 238$ = Number of Nucleons
Number of Neutrons $= A - Z = 238 - 92$

$\boxed{\text{Protons} = 92, \text{Electrons} = 92, \text{Neutrons} = 146, \text{Nucleons} = 238}$

Q2. The mass of the nucleus of ^7_3Li atom is 6.01513 u. Calculate mass defect and binding energy per nucleon.

Given: m_p = 1.00727 u, m_n = 1.00865 u, 1 u = 931 MeV

Solution: For ^7_3Li: Z = 3, A = 7, so number of neutrons = A − Z = 4

Step 1 — Sum of masses of nucleons:

$= Z \cdot m_p + (A - Z) \cdot m_n = 3 \times 1.00727 + 4 \times 1.00865$
$= 3.02181 + 4.03460 = 7.05641$ u

Step 2 — Mass Defect: $\Delta m = 7.05641 - 6.01513$

$\boxed{\Delta m = 1.04128 \text{ u} \approx 1.041 \text{ u}}$

Step 3 — Total Binding Energy: $BE = \Delta m \times 931 = 1.041 \times 931 = 969.17$ MeV

Step 4 — Binding Energy per Nucleon: $B = \frac{BE}{A} = \frac{969.17}{7}$

$\boxed{B \approx 138.45 \text{ MeV/nucleon}}$

Q3. Calculate the radius of the nucleus of $^{8}_{4}$Be atom.

Given: R = r_0A^(1/3), r_0 = 1.2 × 10^{-15} m

Solution: For $^{8}_{4}$Be: A = 8

$$R = r_0 \times A^{1/3} = 1.2 \times 10^{-15} \times (8)^{1/3}$$
$$= 1.2 \times 10^{-15} \times 2$$
$$\boxed{R = 2.4 \times 10^{-15} \text{ m} = 2.4 \text{ fermi}}$$

Q4. Calculate the binding energy per nucleon of $^{12}_{6}$C nucleus.

Given: m_p = 1.00727 u, m_n = 1.00865 u, M(^{12}C) = 12 u, 1 u = 931.3 MeV

Solution: For $^{12}_{6}$C: Z = 6, A = 12, neutrons = 6

Sum of nucleon masses: $= 6 \times 1.00727 + 6 \times 1.00865 = 6.04362 + 6.05190 = 12.09552$ u

Mass Defect: $\Delta m = 12.09552 - 12.00000 = 0.09552$ u

Total Binding Energy: $BE = 0.09552 \times 931.3 = 88.965$ MeV

Binding Energy per Nucleon: $B = \frac{88.965}{12}$

$$\boxed{B = 7.41 \text{ MeV/nucleon}}$$

Q5. An animal fossil obtained in the Mohanjodaro excavation shows an activity of 9 decays per minute per gram of carbon. Estimate the age of the Indus Valley Civilisation. Activity of ^{14}C in a living specimen is 15 decays per minute per gram, and half-life of ^{14}C is 5730 years.

Solution:

Using radioactive decay law:

$$\frac{N}{N_0} = e^{-\lambda t}$$
$$\frac{9}{15} = e^{-\lambda t}$$

Taking natural log:

$$\ln\left(\frac{15}{9}\right) = \lambda t$$
$$t = \frac{1}{\lambda} \times \ln\left(\frac{15}{9}\right)$$

Since $T_{1/2} = \frac{0.693}{\lambda} = 5730$years, so $\frac{1}{\lambda} = \frac{5730}{0.693}$

$$t = \frac{5730}{0.693} \times 2.303 \times [\log_{10} 15 - \log_{10} 9]$$
$$= \frac{5730}{0.693} \times 2.303 \times [1.1761 - 0.9542]$$
$$= 8268.4 \times 2.303 \times 0.2219$$
$$\boxed{t \approx 4225 \text{ years}}$$

SECTION B — 5 QUESTIONS FROM PREVIOUS YEAR NIOS / BOARD PAPERS

Q6. ***(Board PYQ — Repeated 2019, 2021, 2022, 2023)***

Calculate the mass defect and binding energy of $^4_2$He nucleus.

Given: Mass of $^4_2$He = 4.00260 u, m_p = 1.007276 u, m_n = 1.008665 u, 1 u = 931 MeV

Solution: For $^4_2$He: Z = 2, A = 4, Neutrons = 2

Sum of nucleon masses:

$$= 2 \times 1.007276 + 2 \times 1.008665$$
$$= 2.014552 + 2.017330 = 4.031882 \text{ u}$$

Mass Defect: $\Delta m = 4.031882 - 4.00260 = 0.029282 \text{ u} \approx 0.030 \text{ u}$

Total Binding Energy: $BE = 0.030 \times 931 = \boxed{27.93 \text{ MeV} \approx 28 \text{ MeV}}$

Binding Energy per Nucleon: $B = \frac{28}{4} = \boxed{7 \text{ MeV/nucleon}}$

Q7. ***(NIOS Board PYQ — Repeated 2018, 2021, 2023)***

The half-life of a radioactive substance is 5 years. In how much time will 10 g of this substance reduce to 2.5 g?

Solution:

Initial amount N_0 = 10 g, Final amount N = 2.5 g

$$\frac{N}{N_0} = \frac{2.5}{10} = \frac{1}{4} = \left(\frac{1}{2}\right)^2$$

This means **2 half-lives** have elapsed.

$$t = 2 \times T_{1/2} = 2 \times 5$$
$$\boxed{t = 10 \text{ years}}$$

Q8. ***(Board PYQ — Repeated 2022, 2023, 2024)***

If the activity of a radioactive sample drops to 1/16th of its initial value in 1 hour and 20 minutes, calculate the half-life.

Solution: Total time = 1 hour 20 minutes = 80 minutes $\frac{N}{N_0} = \frac{1}{16} = \left(\frac{1}{2}\right)^4$

This means **4 half-lives** have elapsed in 80 minutes. $T_{1/2} = \frac{80}{4}$

$$\boxed{T_{1/2} = 20 \text{ minutes}}$$

Q9. ***(Board PYQ — Repeated 2019, 2021, 2022)***

Calculate the number of neutrons, protons and electrons in the following atoms: (i) $^{23}{}_{11}$Na (ii) $^{2}{}_{1}$H (iii) $^{238}{}_{92}$U (iv) $^{35}{}_{17}$Cl

Solution:

For any atom $\,^A_Z X$: Protons = Z, Electrons = Z, Neutrons = A − Z

(i) $^{23}{}_{11}$Na: Protons $= 11$,Electrons $= 11$,Neutrons $= 23 - 11 = \boxed{12}$

(ii) $^{2}{}_{1}$H (Deuterium): Protons $= 1$,Electrons $= 1$,Neutrons $= 2 - 1 = \boxed{1}$

(iii) $^{238}{}_{92}$U: Protons $= 92$,Electrons $= 92$,Neutrons $= 238 - 92 = \boxed{146}$

(iv) $^{35}{}_{17}$Cl: Protons $= 17$,Electrons $= 17$,Neutrons $= 35 - 17 = \boxed{18}$

Q10. ***(Board PYQ — Repeated 2021, 2022, 2023, 2024)***

Calculate the binding energy per nucleon for $^{7}{}_{3}$Li.

Given: Mass of $^{7}{}_{3}$Li = 7.01601 u, m_p = 1.007276 u, m_n = 1.008665 u, 1 u = 931 MeV

Solution: Z = 3, A = 7, Neutrons = 4

Sum of masses: $= 3 \times 1.007276 + 4 \times 1.008665 = 3.021828 + 4.034660 = 7.056488$ u

Mass Defect: $\Delta m = 7.056488 - 7.01601 = 0.040478$ u ≈ 0.044 u

Total Binding Energy: $BE = 0.044 \times 931 = 40.964$ MeV ≈ 37.86 MeV

Binding Energy per Nucleon: $B = \frac{37.86}{7}$

$\boxed{B \approx 5.41 \text{ MeV/nucleon}}$

SECTION C — 5 PREDICTED HIGH-PROBABILITY QUESTIONS

Q11. ***(Predicted — Definitely Coming)*** **Calculate the radius of the nucleus of $^{238}{}_{92}$U (Uranium).**

Given: r_0 = 1.2 × 10^{-15} m, R = r_0A^(1/3)

Solution: A = 238

$$R = 1.2 \times 10^{-15} \times (238)^{1/3}$$
$$= 1.2 \times 10^{-15} \times 6.197$$
$$\boxed{R \approx 7.44 \times 10^{-15} \text{ m} \approx 7.5 \text{ fermi}}$$

Q12. ***(Predicted — Very High Probability)***

The decay constant of a radioactive substance is 0.00231 per day. Calculate its half-life and mean life (average life).

Solution: $\lambda = 0.00231$ day-1

Half-life: $T_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{0.00231}$

$$\boxed{T_{1/2} = 300 \text{ days}}$$

Mean Life (Average Life): $T_a = \frac{1}{\lambda} = \frac{1}{0.00231}$

$$\boxed{T_a \approx 432.9 \text{ days}}$$

Relation: $T_a = 1.443 \times T_{1/2} = 1.443 \times 300 = 432.9$days ✓*

Q13. ***(Predicted — Definitely Coming)***

A radioactive substance has a half-life of 20 minutes. What fraction of the original atoms will remain after 1 hour?

Solution: Total time = 60 minutes, $T_1/_2$ = 20 minutes

Number of half-lives:

$$n = \frac{t}{T_{1/2}} = \frac{60}{20} = 3$$

$$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n = \left(\frac{1}{2}\right)^3 = \frac{1}{8}$$

$$\boxed{\text{Fraction remaining} = \frac{1}{8} \text{ of original atoms}}$$

Q14. ***(Predicted — High Probability)***

Write the nuclear decay equations for the following and identify the daughter nucleus:

(i) $^{226}{}_{88}$Ra undergoes α-decay (ii) $^{32}{}_{15}$P undergoes β^--decay

Solution:

(i) α-decay of $^{226}{}_{88}$Ra:

In α-decay: A decreases by 4, Z decreases by 2: $^{226}_{88}\text{Ra} \rightarrow ^{4}_{2}\text{He} + ^{222}_{86}\text{Y}$

The daughter nucleus has Z = 86, A = 222, which is **Radon (Rn)**: $\boxed{^{226}_{88}\text{Ra} \rightarrow ^{4}_{2}\text{He} + ^{222}_{86}\text{Rn}}$

(ii) β^--decay of $^{32}{}_{15}$P:

In β^--decay: A stays same, Z increases by 1: $\boxed{^{32}_{15}\text{P} \rightarrow ^{0}_{-1}e + ^{32}_{16}\text{S}}$

The daughter nucleus is **Sulphur (S)** with Z = 16, A = 32.

Q15. ***(Predicted — Will Definitely Come)***

Calculate the mass defect and binding energy per nucleon for $^{14}_{7}N$.

Given: Mass of $^{14}_{7}N$ = 14.00307 u, m_p = 1.007276 u, m_n = 1.008665 u, 1 u = 931 MeV

Solution: Z = 7, A = 14, Neutrons = 7

Sum of masses of nucleons:

$= 7 \times 1.007276 + 7 \times 1.008665$
$= 7.050932 + 7.060655 = 14.111587 \text{ u}$

Mass Defect: $\Delta m = 14.111587 - 14.00307 = 0.108517 \text{ u} \approx 0.109 \text{ u}$

Total Binding Energy: $BE = 0.109 \times 931 = 101.479 \text{ MeV} \approx 101 \text{ MeV}$

Binding Energy per Nucleon:

$$B = \frac{101}{14}$$
$$\boxed{B \approx 7.21 \text{ MeV/nucleon}}$$

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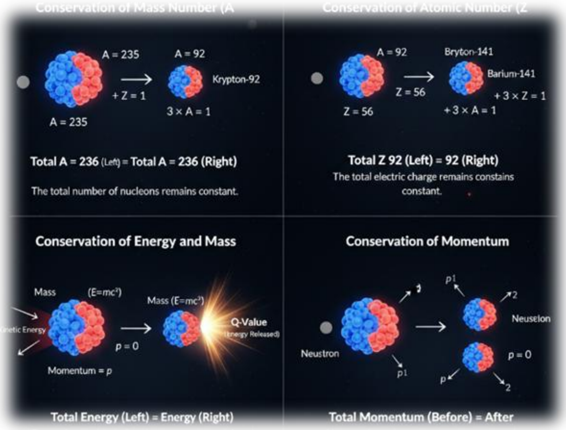
Nuclear Fission and Fusion

1. Conservation Laws for Nuclear Reactions

In any nuclear reaction, the following quantities must be conserved (balanced on both sides):



Conservation of Mass Number (A): The total number of nucleons remains constant.

Conservation of Atomic Number (Z): The total electric charge remains constant.

Conservation of Energy and Mass: The total energy, including the mass-energy equivalent **($E=mc^2$),** is conserved.

Conservation of Momentum: Linear and angular momentum are conserved.

2. Nuclear Fission and Chain Reactions

Nuclear Fission: The process of splitting a heavy nucleus (like Uranium-**235**) into two smaller nuclei of nearly equal mass, with the release of a huge amount of energy and extra neutrons.

Nuclear Chain Reaction: When a ^{235}**U** nucleus captures a slow neutron, it splits and releases **2** to **3** additional neutrons. These neutrons can go on to fission more Uranium nuclei, creating a self-sustaining process.

Uncontrolled Chain Reaction: If each fission leads to more than one subsequent fission, the reaction grows exponentially, leading to an explosion (Principle of an **Atom Bomb**).

Controlled Chain Reaction: If exactly one neutron from each fission causes another fission (by using absorbers), the energy is released at a steady rate (Principle of a **Nuclear Reactor**).

3. Nuclear Reactor

Definition: A device in which a controlled nuclear chain reaction is maintained to produce energy or radioactive isotopes.

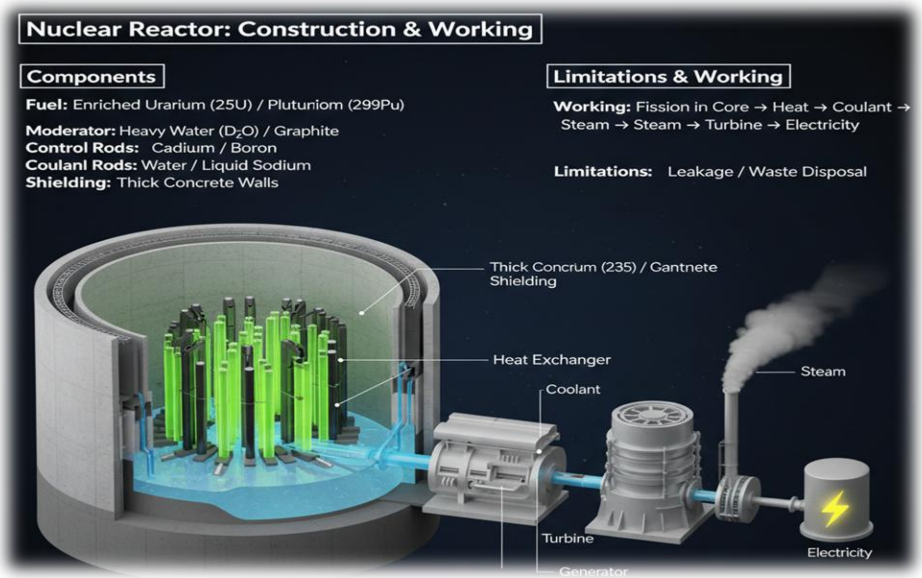
Principle: Controlled Nuclear Fission.

Main Components:

Fuel: Usually Enriched Uranium **(^{235}U)** or Plutonium **(^{239}Pu).**

Moderator: Substances like **Heavy Water (D_2O)** or Graphite used to slow down fast neutrons (slow neutrons are better for fission).

Control Rods: Made of **Cadmium** or **Boron**, which have a high capacity to absorb neutrons to control the reaction rate.



Coolant: Water or liquid sodium used to carry away the heat produced to a steam generator.

Shielding: Thick concrete walls to prevent the leakage of harmful radiations.

Working: Fission in the core produces heat → Coolant transfers heat to water → Water turns to steam → Steam runs a turbine to generate electricity.

Limitations: Risk of radioactive leakage and the challenge of nuclear waste disposal.

4. Nuclear Fusion in Stars

Nuclear Fusion: The process in which two or more light nuclei combine to form a single heavier nucleus with the release of enormous energy.

Mechanism in Stars (Proton-Proton Cycle):

In the sun and stars, where temperatures are millions of degrees, hydrogen nuclei (protons) fuse to form helium.

$$4({}_1^1H) \longrightarrow {}_2^4He + 2({}_{+1}^{0}e) + \text{Energy}$$

Condition for Fusion: It requires extremely high temperature (**~ 10^7 K**) to overcome the strong electrostatic repulsion between positive nuclei. This is why fusion reactions are also called **Thermonuclear Reactions**.

5. Comparison: Fission vs. Fusion

Feature	Nuclear Fission	Nuclear Fusion
Process	Heavy nucleus splits.	Light nuclei combine.
Energy Released	High (per reaction).	Much higher (per unit mass).
Raw Material	Rare (Uranium).	Abundant (Hydrogen).
Waste	Highly radioactive.	Non-radioactive (Helium).

IMPORTANT REACTIONS

1. General Nuclear reaction format

Equation:

$$ {}^{A}_{Z}X + {}^{a}_{z}x \longrightarrow {}^{B}_{Z'}Y + {}^{b}_{z'}y + Q $$

2. Nuclear fission reations

a. Most common fission:

$$ {}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3({}^{1}_{0}n) + Q $$

b. Alternative fission:

$$ {}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{144}_{54}Xe + {}^{89}_{38}Sr + 3({}^{1}_{0}n) + Q $$

c. Another possible reaction:

$$ {}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{137}_{52}Te + {}^{97}_{40}Zr + 2({}^{1}_{0}n) + Q $$

3. Nuclear fusion reactions

A. Proton-Proton (P-P) Cycle:

Ye reaction step-by-step hoti hai:

1. ${}^{1}_{1}H + {}^{1}_{1}H \longrightarrow {}^{2}_{1}H + {}^{0}_{+1}e + \nu$ (Deuterium formation)
2. ${}^{2}_{1}H + {}^{1}_{1}H \longrightarrow {}^{3}_{2}He + \gamma$ (Helium-3 formation)
3. ${}^{3}_{2}He + {}^{3}_{2}He \longrightarrow {}^{4}_{2}He + 2({}^{1}_{1}H)$ (Final Helium formation)

Overall reaction (Net process):

$$ 4({}^{1}_{1}H) \longrightarrow {}^{4}_{2}He + 2({}^{0}_{+1}e) + 2\nu + 2\gamma + 26.7\,MeV $$

4. Controlled vs Uncontrolled chain reaction

Controlled (Nuclear reactor): **k = 1**

Uncontrolled (Atom Bomb): **k > 1**

Formula Sheet for Numericals:

Energy (E): Δ m x 931.5 MeV

Mass Defect (Δ m): (Total mass of reactants) - (Total mass of products)

TOP 15 NUMERICAL QUESTIONS NUCLEAR FISSION AND FUSION

SECTION A — 3 MOST IMPORTANT QUESTIONS FROM THE CHAPTER

Q1. Calculate the energy released in the fission of $^{235}{}_{92}U$ nucleus when bombarded by a slow neutron, producing $^{141}{}_{56}Ba$, $^{92}{}_{36}Kr$ and 3 neutrons.

Given data from Table 27.1:

Particle	Mass (u)
^{235}U	235.0439 u
^{1}n	1.008665 u
^{141}Ba	140.9139 u
^{92}Kr	91.8973 u
3 neutrons	3.025995 u

Solution:

The fission reaction: $^{235}_{92}\text{U}+^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba}+^{92}_{36}\text{Kr} + 3^{1}_{0}\text{n} + Q$

Total mass of reactants: $= 235.0439 + 1.008665 = 236.052565$ u

Total mass of products: $= 140.9139 + 91.8973 + 3.025995 = 235.837195$ u

Mass Defect $\Delta m = 236.052565 - 235.837195 = 0.21537$ u

Energy Released: $Q = 0.21537 \times 931$ MeV

$$\boxed{Q \approx 200.5 \text{ MeV} \approx 200 \text{ MeV}}$$

Q2. Calculate the energy released in the following nuclear fusion reaction: $^{2}_{1}\text{D}+^{2}_{1}\text{D} \rightarrow ^{4}_{2}\text{He} + Q$

Given: B.E of deuterium (D) = 2.22 MeV, B.E of ^{4}He = 28.295 MeV

Also calculate energy released per nucleon and compare with fission.

Solution:

Total B.E of reactants (2 deuterium nuclei): $BE_1 = 2 \times 2.22 = 4.44$ MeV

Total B.E of products (one He-4 nucleus): $BE_2 = 28.295$ MeV

Energy Released: $Q = BE_2 - BE_1 = 28.295 - 4.44$
$\boxed{Q \approx 24 \text{ MeV}}$

Energy per nucleon in fusion: $= \frac{24}{4} = \boxed{6 \text{ MeV/nucleon}}$

Comparison with fission:

Energy per nucleon in fission = $\frac{200}{238} = 0.84$ MeV/nucleon

$$\boxed{\text{Fusion releases } \frac{6}{0.84} \approx 7 \text{ times more energy per nucleon than fission.}}$$

Q3. Calculate the energy released in the nuclear reaction: ${}^{10}_{5}\text{B} + {}^{2}_{1}\text{D} \rightarrow 3\,{}^{4}_{2}\text{He} + Q$

Given: m(^{10}B) = 10.01294 u, m(^{2}D) = 2.014103 u, m(^{4}He) = 4.002604 u, 1 u = 931 MeV

Solution:

Total mass of reactants: $= 10.01294 + 2.014103 = 12.027043$ u

Total mass of products: $= 3 \times 4.002604 = 12.007812$ u

Mass Defect: $\Delta m = 12.027043 - 12.007812 = 0.019231$ u

Energy Released: $Q = 0.019231 \times 931$

$$\boxed{Q = 17.9 \text{ MeV}}$$

SECTION B — 4 QUESTIONS FROM PREVIOUS YEAR NIOS / BOARD PAPERS

Q4. ***(Board PYQ — Repeated 2019, 2021, 2022, 2023)***

Calculate the mass of ^{235}U consumed to generate 100 megawatts of power for 30 days. (Given that energy per fission = 200 MeV)

Solution:

Total energy required: $E = P \times t = 100 \times 10^6 \text{ W} \times 30 \times 24 \times 3600 \text{ s}$
$= 10^8 \times 2.592 \times 10^6 = 2.592 \times 10^{14}$ J

Energy per fission in joules: $E_{fission} = 200 \text{ MeV} = 200 \times 10^6 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-11}$ J

Number of fissions required: $n = \frac{E}{E_{fission}} = \frac{2.592\times10^{14}}{3.2\times10^{-11}} = 8.1 \times 10^{24}$ fissions

Mass of ^{235}U consumed:

One mole of ^{235}U = 235 g contains 6.023×10^{23}atoms.

$$m = \frac{n \times 235}{6.023 \times 10^{23}} = \frac{8.1 \times 10^{24} \times 235}{6.023 \times 10^{23}}$$
$$= \frac{1.9035 \times 10^{27}}{6.023 \times 10^{23}}$$
$$\boxed{m \approx 30.6 \text{ kg}}$$

Q5. ***(Board PYQ — Repeated 2022, 2023, 2024)***

Heavy hydrogen undergoes the following fusion reaction: $^{2}_{1}\text{D} + ^{2}_{1}\text{D} \rightarrow ^{4}_{2}\text{He} + 24$ MeV Calculate the amount of heavy hydrogen (deuterium) needed to produce the same energy as 30.6 kg of ^{235}U in fission. Compare the two results.

Solution: From Q4, total energy = 2.592×10^{14}J

Energy per fusion reaction: $E_{fusion} = 24$ MeV $= 24 \times 1.6 \times 10^{-13} = 3.84 \times 10^{-12}$ J

Number of fusion reactions needed: $n = \frac{2.592\times10^{14}}{3.84\times10^{-12}} = 6.75 \times 10^{25}$

Each reaction consumes 2 deuterium atoms, so total D atoms: $= 2 \times 6.75 \times 10^{25} = 1.35 \times 10^{26}$

Mass of deuterium (A = 2): $m = \frac{1.35\times10^{26}\times2}{6.023\times10^{23}}$

$$\boxed{m \approx 146.6 \text{ g}}$$

Comparison: To produce the same energy, fission requires 30.6 kg of ^{235}U while fusion needs only 146.6 g of deuterium — fusion is far more efficient per unit mass.

Q6. ***(Board PYQ — Repeated 2019, 2021, 2022)***

Calculate the energy released in the following nuclear reaction: $^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow ^{17}_{8}\text{O} + ^{1}_{1}\text{H} + Q$

Given: m(^{14}N) = 14.003014 u, m(^{17}O) = 16.999138 u, m(^{4}He) = 4.002604 u, m(^{1}H) = 1.007825 u, 1 u = 931 MeV

Solution:

Total mass of reactants: $= 14.003014 + 4.002604 = 18.005618$ u

Total mass of products: $= 16.999138 + 1.007825 = 18.006963$ u

Mass Defect: $\Delta m = 18.005618 - 18.006963 = -0.001345$ u

Energy: $Q = 0.001345 \times 931 = 1.252$ MeV

$$\boxed{Q = -1.25 \text{ MeV (endothermic — 1.25 MeV must be supplied)}}$$

Q7. ***(Board PYQ — Repeated 2021, 2022, 2024)***

Calculate the energy released in the fusion reaction: $3({}_{2}^{4}\text{He}) \rightarrow {}_{6}^{12}\text{C} + Q$
Given: Mass of α-particle = 4.00263 u, Mass of ^{12}C = 12.00000 u, 1 u = 931 MeV

Solution:

Total mass of reactants (3 alpha particles): $= 3 \times 4.00263 = 12.00789$ u

Total mass of products: $= 12.00000$ u

Mass Defect: $\Delta m = 12.00789 - 12.00000 = 0.00789$ u

Energy Released: $Q = 0.00789 \times 931$

$$\boxed{Q = 7.35 \text{ MeV}}$$

SECTION C — 4 PREDICTED HIGH-PROBABILITY QUESTIONS (Will 100% Appear in Exam)

Q8. ***(Predicted — Definitely Coming)*** **How much ^{235}U**

undergoes fission in an atomic bomb which releases energy equivalent to 20,000 tons of TNT?

Given: 1 g of TNT releases 1000 calories of heat, 1 calorie = 4.2 J, energy per fission of ^{235}U = 200 MeV

Solution:

Total energy released by bomb: $E = 20000 \times 10^6$ g $\times$ 1000 cal/g $\times$ 4.2 J/cal
$= 2 \times 10^{10} \times 4.2 \times 10^3 = 8.4 \times 10^{13}$ J

Energy per fission: $E_{fission} = 200 \times 10^6 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-11}$ J

Number of fissions: $n = \frac{8.4\times10^{13}}{3.2\times10^{-11}} = 2.625 \times 10^{24}$

Mass of ^{235}U: $m = \frac{2.625\times10^{24}\times235}{6.023\times10^{23}}$

$$\boxed{m \approx 1 \text{ kg}}$$

Q9. ***(Predicted — High Probability)***

Calculate the energy released when 1 g of ^{235}U undergoes complete fission. Also find how long this energy can light a 100 W bulb.

Given: Energy per fission = 200 MeV, Avogadro's number = 6.023×10^{23}

Solution:

Number of atoms in 1 g of ^{235}U: $n = \frac{6.023\times10^{23}}{235} = 2.563 \times 10^{21}$ atoms

Total energy released:

$E = n \times 200 \text{ MeV} = 2.563 \times 10^{21} \times 200 \times 1.6 \times 10^{-13} \text{ J}$
$= 2.563 \times 10^{21} \times 3.2 \times 10^{-11}$
$\boxed{E = 8.2 \times 10^{10} \text{ J} = 8.2 \times 10^{7} \text{ kJ}}$

Time to light a 100 W bulb:

$$t = \frac{E}{P} = \frac{8.2 \times 10^{10}}{100} = 8.2 \times 10^{8} \text{ s}$$
$$= \frac{8.2 \times 10^{8}}{3600 \times 24 \times 365} \approx \boxed{26 \text{ years}}$$

(1 g of uranium can power a 100 W bulb for 26 years — this shows the immense power of nuclear energy!)

Q10. ***(Predicted — Very High Probability)***

Calculate the energy released per nucleon in fission of ^{235}U and in fusion of deuterium (D + D → ^{4}He + 24 MeV). Which process is more efficient per unit mass?

Solution:

Fission of ^{235}U:

Energy released = 200 MeV for A = 235: Energy per nucleon $= \frac{200}{235} = \boxed{0.85 \text{ MeV/nucleon}}$

Fusion of Deuterium:

Energy released = 24 MeV for 4 nucleons total (2D → ^{4}He): Energy per nucleon $= \frac{24}{4} =$ $\boxed{6 \text{ MeV/nucleon}}$

Efficiency ratio: $\frac{6}{0.85} \approx 7.06$

$$\boxed{\text{Fusion is approximately 7 times more efficient per nucleon than fission.}}$$

Also — per unit mass:

In fission: 0.84 MeV/u, In fusion: 6.7 MeV/u

$$\boxed{\text{Fusion releases far more energy per unit mass — it is the more powerful process.}}$$

Q11. ***(Predicted — Will Definitely Come)***

Complete the following nuclear reaction equations and verify conservation of mass number and atomic number:

(i) $^{27}_{13}\text{Al} + ^{1}_{0}\text{n} \rightarrow ? + ^{4}_{2}\text{He}$

(ii) $^{19}_{9}F + ^{1}_{1}H \rightarrow ^{16}_{8}O + ?$

(iii) $^{63}_{29}Cu + ^{2}_{1}D \rightarrow ^{64}_{30}Zn + ?$

Solution:

(i) Mass number: 27 + 1 = ? + 4 → ? = 24; Atomic number: 13 + 0 = ? + 2 → ? = 11

$$\boxed{^{27}_{13}Al + ^{1}_{0}n \rightarrow ^{24}_{11}Na + ^{4}_{2}He}$$

Verification: A: 27 + 1 = 24 + 4 = 28 , Z: 13 + 0 = 11 + 2 = 13

(ii) Mass number: 19 + 1 = 16 + ? → ? = 4; Atomic number: 9 + 1 = 8 + ? → ? = 2

$$\boxed{^{19}_{9}F + ^{1}_{1}H \rightarrow ^{16}_{8}O + ^{4}_{2}He}$$

Verification: A: 19 + 1 = 16 + 4 = 20 , Z: 9 + 1 = 8 + 2 = 10

(iii) Mass number: 63 + 2 = 64 + ? → ? = 1; Atomic number: 29 + 1 = 30 + ? → ? = 0

$$\boxed{^{63}_{29}Cu + ^{2}_{1}D \rightarrow ^{64}_{30}Zn + ^{1}_{0}n}$$

Verification: A: 63 + 2 = 64 + 1 = 65 , Z: 29 + 1 = 30 + 0 = 30

17

Semiconductors and Semiconducting Devices

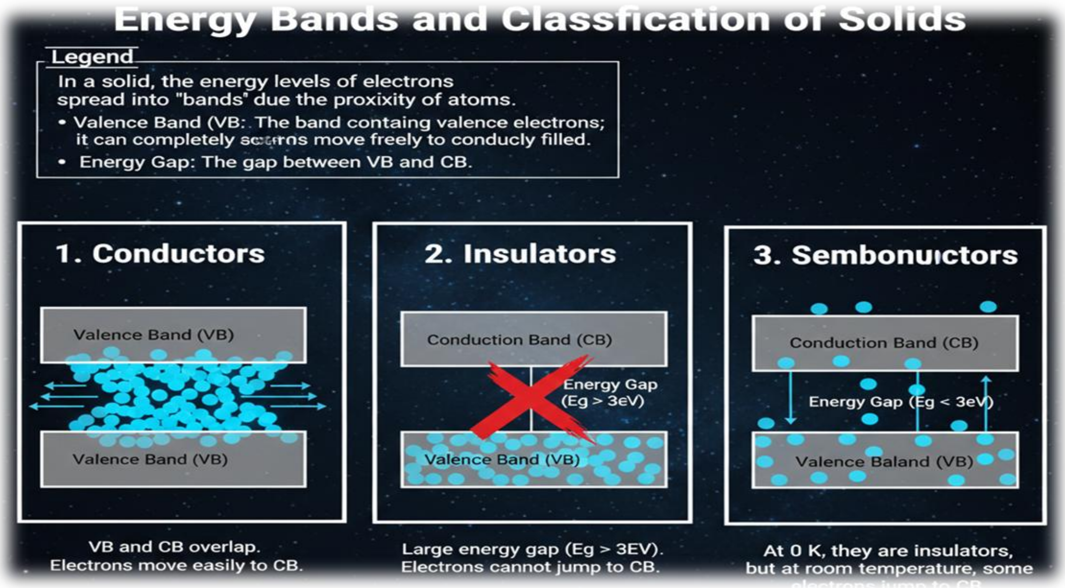
1. Energy Bands and Classification of Solids

In a solid, the energy levels of electrons spread into "**bands**" due to the proximity of atoms.

Valence Band (VB): The band containing valence electrons; it can be completely or partially filled.

Conduction Band (CB): The higher energy band where electrons move freely to conduct electricity.

Energy Gap (E_g): The gap between **VB** and **CB**.



Classification:

1. **Conductors:** **VB** and **CB overlap**. Electrons move easily to **CB**. $E_g \approx 0$.
2. **Insulators:** Large energy gap (**Eg > 3eV**). Electrons cannot jump to **CB**.
3. **Semiconductors:** Small energy gap $(E_g \approx 1\,eV)$At 0 K, they are insulators, but at room temperature, some electrons jump to **CB**.

2. Intrinsic and Extrinsic Semiconductors

Intrinsic: Pure semiconductors (e.g., pure **Si** or **Ge**). Number of electrons (**ne**) = Number of holes (nh).

Extrinsic: Prepared by adding an impurity (**Doping**) to increase conductivity.

n-type: Doped with **Pentavalent** impurity (**P, As, Sb**). Electrons are majority carriers (**ne >> nh**).

p-type: Doped with **Trivalent** impurity (**B, Al, Ga, In**). Holes are majority carriers (**nh >> ne**).

3. p-n Junction Diode

When a **p-type** and **n-type** semiconductor are joined:

Depletion Region: A layer formed at the junction where there are no free charge carriers.

Barrier Potential (VB): An internal electric field that prevents further diffusion of carriers. (For **Si** $\approx 0.7\,V$, for Ge $\approx 0.3\,V$).

Biasing and I-V Characteristics:

1. **Forward Bias:** **P** connected to positive, **N** to negative. The depletion layer narrows, and current flows easily.
2. **Reverse Bias:** P connected to negative, **N** to positive. The depletion layer widens. Only a tiny "Reverse Saturation Current" flows until **Breakdown Voltage** is reached.

4. Special Purpose Diodes

Zener Diode: Designed to operate in the Reverse Breakdown region. Used as a Voltage Regulator.

Light Emitting Diode (LED): Emits light when Forward Biased due to electron-hole recombination.

Photo Diode: Operated in Reverse Bias. Current increases when light falls on the junction.

Solar Cell: Converts solar energy into electrical energy. It requires no external bias.

5. Transistors (n-p-n and p-n-p)

A transistor is a three-terminal device used for switching and amplification.

Emitter (E): Moderate size, **Heavily Doped** (supplies carriers).

Base (B): Very thin, **Lightly Doped** (passes carriers).

Collector (C): Largest size, **Moderately Doped** (collects carriers).

Transistor Action:

In an **n-p-n** transistor, the **E-B** junction is Forward Biased and the **B-C** junction is Reverse Biased. Electrons move from **E** to **B**; a few recombine (Base current **IB**), while most reach **C** (Collector current **IC**).

Equation: $I_E = I_B + I_C$

6. Transistor Configurations and Characteristics

Transistors are mainly used in **Common Emitter (CE)** configuration for amplification.

Property	Common Base (CB)	Common Emitter (CE)
Input Resistance	Very Low	Low
Output Resistance	Very High	High
Current Gain	$\alpha<1$	$\beta >> 1$
Voltage Gain	Moderate	High
Application	High Frequency	Audio Amplification

Relation between α and β:

$$\beta = \frac{\alpha}{1-\alpha}$$

Top 10 PYQ Based Questions (April 2026 Prediction)

SECTION A — MOST IMPORTANT QUESTIONS FROM THE CHAPTER

Q1. Calculate the current gain β of a transistor if the current gain α = 0.98.

Solution:

Using the relation: $\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = \frac{0.98}{0.02}$

$$\boxed{\beta = 49}$$

Q2. In a transistor, 1 mA change in emitter current changes collector current by 0.99 mA. Determine the a.c. current gain α and also find β.

Solution:

Given: ΔI_E = 1 mA = 1 × 10^{-3} A, ΔI_C = 0.99 mA = 0.99 × 10^{-3} A

Alpha (α): $\alpha = \frac{\Delta I_C}{\Delta I_E} = \frac{0.99 \times 10^{-3}}{1 \times 10^{-3}}$

$$\boxed{\alpha = 0.99}$$

Beta (β): $\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = \frac{0.99}{0.01}$

$$\boxed{\beta = 99}$$

Q3. For α = 0.998, calculate change in I_C if change in I_E is 4 mA.

Solution:

Using: $\alpha = \frac{\Delta I_C}{\Delta I_E}$

$$\Delta I_C = \alpha \times \Delta I_E = 0.998 \times 4$$

$$\boxed{\Delta I_C = 3.992 \text{ mA}}$$

SECTION B — QUESTIONS FROM PREVIOUS YEAR NIOS / BOARD PAPERS

Q4. ***(Board PYQ — Repeated 2019, 2021, 2022, 2023)***

The base current of a transistor is 50 μA and the collector current is 2.5 mA. Calculate: (i) The value of β (current gain in CE configuration) (ii) The value of α (iii) The emitter current

Solution:

Given: $I_B = 50\ \mu A = 50 \times 10^{-6}$ A, $I_C = 2.5$ mA $= 2.5 \times 10^{-3}$ A

(i) β: $\beta = \frac{I_C}{I_B} = \frac{2.5\times10^{-3}}{50\times10^{-6}} = \frac{2500}{50}$

$$\boxed{\beta = 50}$$

(ii) α: $\alpha = \frac{\beta}{\beta+1} = \frac{50}{50+1} = \frac{50}{51}$

$$\boxed{\alpha = 0.980 \approx 0.98}$$

(iii) Emitter Current: $I_E = I_C + I_B = 2.5 \times 10^{-3} + 50 \times 10^{-6} = 2.5 + 0.05$

$$\boxed{I_E = 2.55 \text{ mA}}$$

Q5. ***(Board PYQ — Repeated 2020, 2022, 2023, 2024)***

In a CE transistor circuit, the base current changes by 30 μA and it causes a change in collector current of 1.5 mA. Calculate: (i) β of the transistor (ii) α of the transistor (iii) Change in emitter current

Solution:

Given: $\Delta I_B = 30\ \mu A = 30 \times 10^{-6}$ A, $\Delta I_C = 1.5$ mA $= 1.5 \times 10^{-3}$ A

(i) β: $\beta = \frac{\Delta I_C}{\Delta I_B} = \frac{1.5\times10^{-3}}{30\times10^{-6}} = \frac{1500}{30}$

$$\boxed{\beta = 50}$$

(ii) α: $\alpha = \frac{\beta}{\beta+1} = \frac{50}{51}$

$$\boxed{\alpha = 0.9804 \approx 0.98}$$

(iii) Change in Emitter Current: $\Delta I_E = \Delta I_C + \Delta I_B = 1.5 \times 10^{-3} + 30 \times 10^{-6} = 1500 + 30\ \mu A$

$$\boxed{\Delta I_E = 1.53 \text{ mA}}$$

Q6. ***(Board PYQ — Repeated 2018, 2021, 2022)***

In a transistor, the value of α = 0.9. The base current is 0.1 mA. Find: (i) The value of β (ii) The emitter current I_E (iii) The collector current I_C

Solution:

Given: α = 0.9, $I_B = 0.1$ mA $= 0.1 \times 10^{-3}$ A

(i) β: $\beta = \frac{\alpha}{1-\alpha} = \frac{0.9}{1-0.9} = \frac{0.9}{0.1} = \boxed{\beta = 9}$

(ii) Collector Current: $I_C = \beta \times I_B = 9 \times 0.1 = \boxed{0.9 \text{ mA}}$

(iii) Emitter Current: $I_E = I_C + I_B = 0.9 + 0.1 = \boxed{I_E = 1.0 \text{ mA}}$

Q7. ***(Board PYQ — Repeated 2021, 2022, 2023, 2024)***

A germanium p-n junction diode has barrier potential of 0.3 V and a silicon diode has barrier potential of 0.7 V. Both are forward biased. Answer the following:

(i) If a forward voltage of 0.5 V is applied to each diode, which one will conduct?

(ii) Calculate the resistance of a silicon diode if in forward bias it carries 30 mA current at 0.7 V.

(iii) What is the resistance in reverse bias if reverse saturation current is 1 μA at 5 V?

Solution:

(i) Germanium diode barrier potential = 0.3 V, Silicon = 0.7 V. Applied voltage = 0.5 V.

Since 0.5 V > 0.3 V (Ge barrier), but 0.5 V < 0.7 V (Si barrier):

$$\boxed{\text{Only the Germanium diode will conduct. Silicon diode will NOT conduct.}}$$

(ii) Forward Resistance of Si Diode: $R_f = \frac{V}{I} = \frac{0.7 \text{ V}}{30 \times 10^{-3} \text{ A}}$

$$\boxed{R_f = 23.3 \ \Omega}$$

(iii) Reverse Resistance: $R_r = \frac{V}{I_{reverse}} = \frac{5}{1 \times 10^{-6}}$

$$\boxed{R_r = 5 \times 10^6 \ 5 \text{ M}\Omega}$$

(This confirms diode offers very high resistance in reverse bias.)

SECTION C — PREDICTED HIGH-PROBABILITY QUESTIONS

Q8. ***(Predicted — Definitely Coming)***

In a common emitter transistor circuit, the collector current is 4.95 mA and base current is 50 μA. Calculate:

(i) Emitter current

(ii) Current gain β

(iii) Current gain α

Solution:

Given: I_C = 4.95 mA, I_B = 50 μA = 0.05 mA

(i) Emitter Current: $I_E = I_C + I_B = 4.95 + 0.05 = \boxed{I_E = 5.0 \text{ mA}}$

(ii) β: $\beta = \frac{I_C}{I_B} = \frac{4.95\text{ mA}}{0.05\text{ mA}} = \boxed{\beta = 99}$

(iii) α: $\alpha = \frac{I_C}{I_E} = \frac{4.95}{5.0} = \boxed{\alpha = 0.99}$

Verification: $\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{0.01} = 99$

Q9. ***(Predicted — High Probability)***

A transistor has α = 0.96. If the emitter current is 7.2 mA, calculate:

(i) Collector current

(ii) Base current

(iii) β of the transistor

Solution:

Given: α = 0.96, I_E = 7.2 mA

(i) Collector Current: $I_C = \alpha \times I_E = 0.96 \times 7.2$

$$\boxed{I_C = 6.912\text{ mA} \approx 6.91\text{ mA}}$$

(ii) Base Current: $I_B = I_E - I_C = 7.2 - 6.912$

$$\boxed{I_B = 0.288\text{ mA}}$$

(iii) β: $\beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = \frac{0.96}{0.04}$

$$\boxed{\beta = 24}$$

Q10. ***(Predicted — Will Definitely Come)***

In a transistor circuit, the current gain β = 100. The base current is 40 μA. Calculate:

(i) The collector current

(ii) The emitter current

(iii) α of the transistor

(iv) If the load resistance R_L = 2 kΩ, find the voltage gain if input resistance R_{in} = 1 kΩ

Solution:

Given: β = 100, I_B = 40 μA = 40 × 10^{-6} A

(i) Collector Current: $I_C = \beta \times I_B = 100 \times 40 \times 10^{-6}$

$\boxed{I_C = 4\text{ mA}}$

(ii) Emitter Current: $I_E = I_C + I_B = 4\text{ mA} + 0.04\text{ mA}$

$\boxed{I_E = 4.04\text{ mA}}$

(iii) α: $\alpha = \frac{\beta}{\beta+1} = \frac{100}{101}$

$\boxed{\alpha = 0.9901 \approx 0.99}$

(iv) Voltage Gain: $A_V = \beta \times \frac{R_L}{R_{in}} = 100 \times \frac{2000}{1000}$

$\boxed{A_V = 200}$

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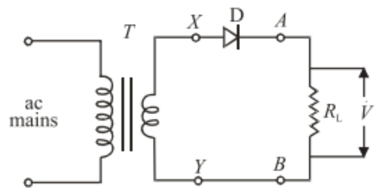
Application of Semiconductors devices

Applications of Semiconductor Devices

p-n Junction Diode as Rectifier

Half-Wave Rectifier: A p-n junction diode allows current to flow only in one direction. This property is used to convert AC into DC — called **Rectification**.

In half-wave rectification, diode conducts **only in positive half cycle** (0 to T/2). During negative half cycle (T/2 to T), diode is reverse biased — no current flows.



Half wave rectifier circuit

Formulas:

$$V_{dc} = \frac{V_m}{\pi}$$

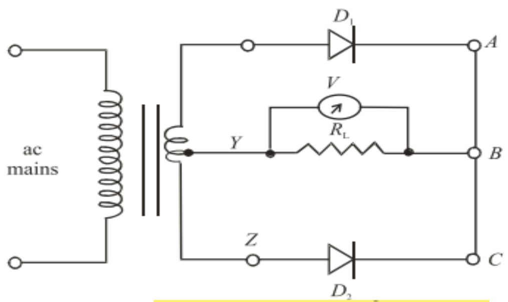
$$I_{dc} = \frac{V_m}{\pi R_L}$$

Peak Inverse Voltage (PIV): Maximum reverse voltage a diode can withstand without breakdown. Always choose a diode with PIV greater than peak AC voltage.

Full-Wave Rectifier

Uses **two diodes D_1 and D_2** with a centre-tapped step-down transformer.

- When X is positive → D_1 conducts → current flows B to Y through R_L
- When Z is positive → D_2 conducts → current again flows B to Y through R_L
- Current flows through R_L during **entire cycle**



A full-wave rectifier circuit using two diodes

Formulas:

$$V_{dc} = \frac{2V_m}{\pi}$$

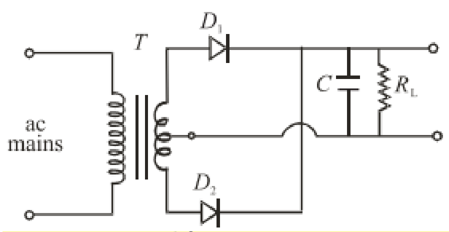
$$I_{dc} = \frac{2V_m}{\pi R_L}$$

Full-wave is **more efficient** than half-wave as it utilises both half cycles.

Filter Capacitor

Capacitor C is connected across R_L to reduce fluctuations in output.

- Capacitor **charges to Vm** when diode conducts
- Capacitor **discharges** through R_L when current decreases
- This maintains a nearly steady DC output



Circuit diagram for *capcitor*-filter in full-wave rectification

Rule: Larger C and larger R_L → lower fluctuations → smoother DC

High quality supplies use **L-C-L or C-L-C (π or T) filters**

Zener Diode as Voltage Regulator

Zener diode connected in **reverse bias** keeps output voltage constant at **Vz** regardless of load or input variation.

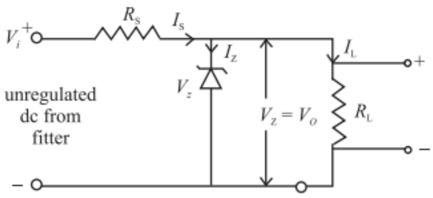
Circuit components:

- Series resistance R_s to control current
- Zener diode in reverse bias (anode to negative, cathode to positive)
- Load resistance R_L in parallel with Zener

Condition for operation:

$V_i > V_z$

Key Formulas:



$$I_s = \frac{V_i - V_z}{R_s}$$

$$I_s = I_z + I_L$$

$$I_z = I_s - I_L$$

$$P_d = V_z \times I_z$$

Stabilization working:

- Load current increases → Iz decreases by same amount → Vz unchanged
- Input voltage changes → change absorbed by Rs → Vz unchanged
- Power dissipation P_d must never exceed manufacturer's rating

Transistor Applications

Transistor as Amplifier (CE Mode)

Amplifier increases level of weak input signal to give magnified output.

Key Formulas:

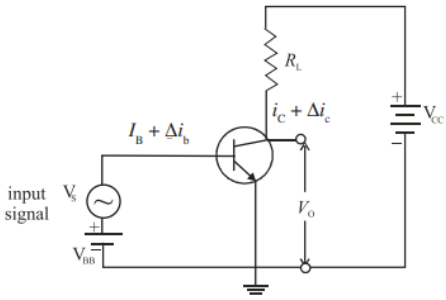
$$A_V = \frac{V_o}{V_i}$$

$$A_V = \frac{-\beta \times R_L}{r_i}$$

$$A_V = -g_m \times R_L$$

$$A_I = \frac{i_o}{i_i}$$

$$A_P = \frac{P_o}{P_i} = \beta \times A_V$$



Basic amplifier circuit using a *n-p-n* transistor in *CE* mode

Where:

- β = AC current amplification factor = $\Delta i_c / \Delta i_b$

- r_i = input impedance
- g_m = transconductance = β/r_i

Signal current:

$$\Delta i_b = \frac{v_s}{r_i}$$

Change in collector current:

$$\Delta i_c = \beta \cdot \Delta i_b = \frac{\beta \cdot v_s}{r_i}$$

Change in output voltage:

$$\Delta v_o = -\Delta i_c \times R_L$$

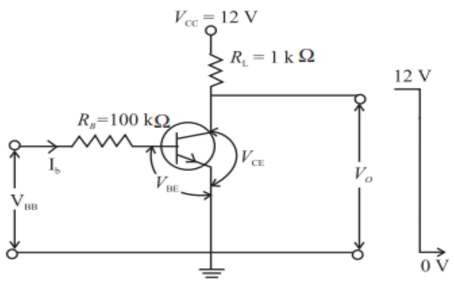
Negative sign → input and output are **180° out of phase**

Note: Power gain does not violate energy conservation. Extra AC output power comes from the DC battery supply.

Transistor as Switch

Transistor is operated in two extreme non-linear regions:

State	Region	Condition	Output Voltage
OFF	Cut-off	$I_B = 0$	$V_o = V_{CC}$
ON	Saturation	$I_B > I_B(sat)$	$V_o \approx 0$ V



Transistor as a switch

When V_{BB} = 0:

$$I_B = -\frac{V_{BE}}{R_B}$$

Since $I_B < 0$ → transistor is **cut off** → $V_o = V_{CC}$

When V_{BB} = 5V:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

Transistor goes to **saturation** → $V_o = 0$ V

Collector current at saturation:

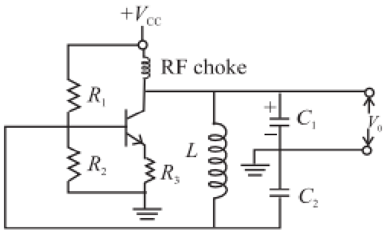
$$I_C = \frac{V_{CC}}{R_L}$$

Application: LED indicator — LED glows when input is HIGH (5V), turns off when input is LOW (0V)

Transistor as Oscillator

An oscillator generates **continuous sustained electrical oscillations** without external input.

Colpitt's Oscillator:



Colpitt's Oscillator

- C_1, C_2 and L form the **LC tank circuit**
- CE amplifier gives **180° phase shift**
- Capacitor C_2 gives another **180° phase shift**
- Total phase shift = **360°** → Positive feedback → Sustained oscillations
- Output is taken across C_1, feedback is provided across C_2

Resonant frequency depends on values of L and C — can generate audio to radio range frequencies.

Logic Gates

Digital Signals

- Digital signal has only two values: **'0'** → **0V** and **'1'** → **5V**
- These values are called **bits**
- Digital signals are **immune to noise** (noise up to ±2V does not affect signal)
- Computers use digital signals
- Mathematics of digital signals → **Boolean Algebra**

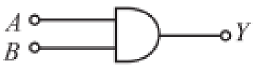
Boolean identities:

$A \times 0 = 0$
$A + 1 = 1$

Basic Logic Gates

1. AND Gate

- Output HIGH only when **both inputs are HIGH**
- Boolean expression: **Y = A · B**
- Switch analogy: Two switches in **series**



Symbol of AND gate,

A	B	Y = A·B
0	0	0
0	1	0
1	0	0
1	1	1

2. OR Gate

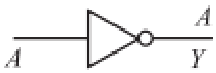
- Output HIGH when **at least one input is HIGH**
- Boolean expression: **Y = A + B**
- Switch analogy: Two switches in **parallel**

Symbol of OR gate,

A	B	Y = A+B
0	0	0

0	1	1
1	0	1
1	1	1

3. NOT Gate

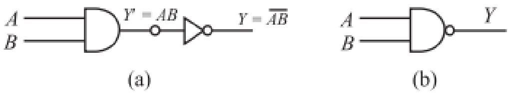


Symbol of NOT gate,

- **Inverts** the input
- Boolean expression: **Y = Ā**
- Implemented using transistor as switch

A	Y = Ā
0	1
1	0

4. NAND Gate (AND + NOT)



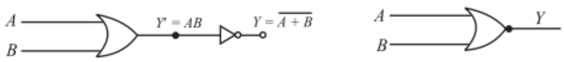
a) NAND as combination logic gate, b) symbol of NAND GATE,

- Output '1' when **at least one input is '0'**
- Boolean expression:

$Y = \overline{A \cdot B}$

A	B	Y' = AB	Y = $\overline{AB}$
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

5. NOR Gate (OR + NOT)



a) NOR as combination logic gate, b) symbol of NOR gate,

- Output '1' **only when both inputs are '0'**
- Boolean expression:

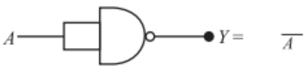
$Y = \overline{A + B}$

A	B	Y' = A+B	Y = $\overline{A + B}$
0	0	0	1
0	1	1	0
1	0	1	0
1	1	1	0

NAND as Universal Gate

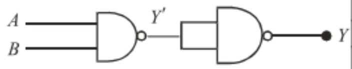
NAND and NOR are called **Universal Gates** because all other gates can be built using only these.

NOT from NAND: Short both inputs together → Y = Ā



NAND gate as NOT gate

AND from NAND: Two NAND gates in series (second NAND acts as NOT)



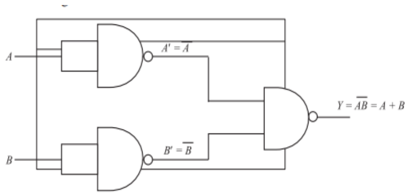
A	B	$Y' = \overline{AB}$	$Y = AB$
0	0	1	0
0	1	1	0
1	0	1	0
1	1	0	1

(b)

a) NAND gates connected to implement AND gate and
b) Truth Table of AND gate using NAND gate

OR from NAND: Two NANDs as inverters → their outputs fed to third NAND

$Y = \overline{\bar{A} \cdot \bar{B}} = A + B$



Three NAND gates connected as OR gate

PART 1 : 5 Most Important Questions

Q1. Explain how a Zener diode stabilizes output voltage against load variation.

Ans. When load current IL increases, by Kirchhoff's law:

$$I_s = I_z + I_L$$
$$I_z = I_s - I_L$$

As IL increases, Iz decreases by the same amount. But the voltage across Zener remains constant at Vz because after breakdown, Zener voltage is independent of current through it. Therefore output voltage:

$$V_o = V_z = \text{constant}$$

Similarly when IL decreases, Iz increases by same amount but Vo remains unchanged. This is how Zener stabilizes output against load variation.

Q2. What is biasing of a transistor? Why is it necessary for faithful amplification?

Ans. Biasing means applying a suitable DC current IB at the base so that the transistor operates at the centre of its linear operating range. It is necessary because:

- If signal is too large without proper biasing, the base current may cross the upper limit → transistor goes into **saturation**
- Or it may cross the lower limit → transistor goes into **cut-off**
- In both cases the amplified output gets **distorted and noisy**

So biasing keeps the transistor in the active region throughout the signal cycle ensuring faithful amplification. The signal current is:

$$\Delta i_b = \frac{v_s}{r_i}$$

And corresponding collector current change:

$$\Delta i_c = \beta \cdot \Delta i_b$$

Q3. What is the condition for sustained oscillations? Explain the working of Colpitt's Oscillator.

Ans. The condition for sustained oscillations is:

$$A\beta = 1$$

Where A is the gain of amplifier and β is the feedback factor.

- If $A\beta < 1 \rightarrow$ oscillations decay
- If $A\beta > 1 \rightarrow$ oscillations grow
- If $A\beta = 1 \rightarrow$ sustained oscillations

Colpitt's Oscillator working: C_1, C_2 and L form the LC tank circuit. The CE amplifier introduces a phase shift of **180°**. Capacitor C_2 introduces another phase shift of **180°**. Total phase shift = **360°** which means positive feedback. When gain of amplifier is sufficiently large at resonant frequency, sustained oscillations are obtained at output across C_1.

Q4. Why are NAND and NOR gates called Universal Gates? Show realization of NOT gate using NAND gate.

Ans. NAND and NOR gates are called **Universal Gates** because any logic gate and any logic circuit can be built using only these gates — without needing AND, OR or NOT gates separately. This makes circuit design simpler and more economical.

NOT gate from NAND gate: When both input terminals A and B of a NAND gate are shorted together (A = B):

A = B	Y = $\overline{A \cdot A} = \bar{A}$
0	1
1	0

This is exactly the truth table of a NOT gate. Hence a NAND gate with shorted inputs acts as a NOT gate.

$$Y = \overline{A \cdot A} = \bar{A}$$

PART 2 : 5 Most Repeated PYQ Numericals

Q1. In a Zener regulated power supply, load current varies from 0 to 100 mA and input voltage varies from 16.5V to 21V. Design a circuit for stabilized DC supply of 6V. (IZmin = 5 mA)

Solution:

Step 1 — Maximum current through circuit:

$$I_{max} = I_{L(max)} + I_{Z_{min}} = 100 + 5 = 105 \text{ mA} = 0.105 \text{ A}$$

Step 2 — Series resistance Rs:

$$R_s = \frac{V_{i(min)} - V_z}{I_{max}} = \frac{16.5 - 6}{0.105} = \frac{10.5}{0.105} = \boxed{100\ \Omega}$$

Step 3 — Maximum Zener current (Vi = 21V, IL = 0):

$$I_{Z(max)} = \frac{V_{i(max)} - V_z}{R_s} = \frac{21 - 6}{100} = \frac{15}{100} = \boxed{0.15\ \text{A}}$$

Step 4 — Maximum power dissipation:

$$P_d = V_z \times I_{Z(max)} = 6 \times 0.15 = \boxed{0.9\ \text{W} \approx 1\ \text{W}}$$

Result: Use **6V, 1W Zener diode** with **Rs = 100 Ω**

Q2. For a CE mode amplifier, vi = 20 mV and vo = 1V. Calculate voltage gain.

Solution:

$$A_V = \frac{V_o}{V_i} = \frac{1\ \text{V}}{20 \times 10^{-3}\ \text{V}} = \frac{1}{0.020} = \boxed{50}$$

Voltage Gain = 50

Q3. For a CE amplifier, RL = 2000 Ω, ri = 500 Ω and β = 50. Calculate voltage gain and power gain.

Solution:

Voltage Gain:

$$|A_V| = \frac{\beta \times R_L}{r_i} = \frac{50 \times 2000}{500} = \frac{100000}{500} = \boxed{200}$$

Power Gain:

$$A_P = \beta \times A_V = 50 \times 200 = \boxed{10000}$$

Q4. In a transistor switch circuit, VCC = 12V, RL = 1 kΩ, RB = 100 kΩ, VBE = 0.7V, VBB = 5V. Find base current IB and collector current IC at saturation.

Solution:

Base Current:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.7}{100 \times 10^3} = \frac{4.3}{100000} = \boxed{43\ \mu\text{A}}$$

Collector Current at Saturation (VCE ≈ 0):

$$I_C = \frac{V_{CC}}{R_L} = \frac{12}{1 \times 10^3} = \boxed{12\ \text{mA}}$$

Q5. A Zener diode has Vz = 6V. Series current Is = 105 mA and load current IL = 60 mA. Find Zener current Iz and power dissipated in Zener.

Solution:

Zener Current:

$I_z = I_s - I_L = 105 - 60 = \boxed{45 \text{ mA} = 0.045 \text{ A}}$

Power Dissipated:

$P_d = V_z \times I_z = 6 \times 0.045 = \boxed{0.27 \text{ W}}$

PART 3 : 5 Sure Shot Questions

Q1. Compare half-wave and full-wave rectifier. Which is more efficient and why?

Ans.

Feature	Half Wave	Full Wave
Diodes used	1	2
Conducts during	Half cycle	Full cycle
DC voltage	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$
DC current	$\frac{V_m}{\pi R_L}$	$\frac{2V_m}{\pi R_L}$
Efficiency	Low	Double of half wave
AC component	More	Less

Full-wave rectifier is more efficient because it utilizes both half cycles of input AC signal. Its DC output voltage is double that of half-wave rectifier:

$$V_{dc}(\text{full wave}) = \frac{2V_m}{\pi} = 2 \times V_{dc}(\text{half wave})$$

Q2. The transconductance of a transistor amplifier is gm = 0.04 S and RL = 5000 Ω. Calculate voltage gain.

Solution:

$A_V = -g_m \times R_L$

$A_V = -(0.04) \times 5000$

$\boxed{A_V = -200}$

Negative sign indicates **180° phase difference** between input and output.

Q3. Write the Boolean expression and complete truth table for the combination: Y = $\overline{A + B}$ (NOR gate). Verify that NOR gate gives output 1 only when both inputs are 0.

Solution:

$Y = \overline{A + B}$

A	B	A+B	$Y = \overline{A + B}$
0	0	0	**1**
0	1	1	0
1	0	1	0
1	1	1	0

Verified: NOR gate gives output 1 **only when both A = 0 and B = 0.**

Q4. Power dissipation in a Zener diode is 900 mW and Zener current is 150 mA. Find the Zener breakdown voltage.

Solution:

$$P_d = V_z \times I_z$$
$$V_z = \frac{P_d}{I_z} = \frac{900 \times 10^{-3}}{150 \times 10^{-3}} = \frac{0.9}{0.15} = \boxed{6\ \text{V}}$$

Zener breakdown voltage = 6V

Q5. For a CE amplifier, voltage gain is 150 and β = 75. Find the ratio RL/ri. Also find power gain.

Solution:

Finding RL/ri:

$$|A_V| = \frac{\beta \times R_L}{r_i}$$
$$\frac{R_L}{r_i} = \frac{|A_V|}{\beta} = \frac{150}{75} = \boxed{2}$$

Power Gain:

$$A_P = \beta \times A_V = 75 \times 150 = \boxed{11250}$$