1. **(b)**For a short electric dipole on its axis, electric field varies as:
$E \propto \frac{1}{p^2}$
Force on a charge :
$F = qE \propto \frac{1}{r^3}$
When distance becomes 2r.
$F' = \frac{F}{(2)^3} = \frac{F}{8}$
2. **(a)** For a metallic conductor, resistance increases linearly with temperature:
$R = R_0(1 + \alpha T)$
So the graph must be a straight line with positive slope and non-zero resistance at $T = 0$.
3. **(d)** Potential difference in open circuit = emf E = 8 V
When current I = 4A, terminal voltage V = 4V
Using:
$V = E - Ir$
$4 = 8 - 4r$
$4r = 4$
$r = 1\Omega$
4. **(a)** Drift velocity:
$v_d = \frac{I}{n \in A}$
Since current I is constant,
$v_d \propto \frac{1}{A}$
So v_d decreases hyperbolically with increase in area.
5. **(a)** Diamagnetic substances are repelled by magnetic fields.
Hence they are repelled by both north and south poles. give 2nd solution
6. **(c)** Maximum induced emf in rotating coil:
$E_0 = NBA\omega$
Given:
$N = 40, B = 3 \times 10^{-2} T$
$r = 8 \text{ cm} = 0.08 \text{ m}$
$A = \pi r^2 = \pi(0.08)^2$
$\omega = \frac{25}{\pi} \text{rads}^{-1}$
$E_0 = 40 \times 3 \times 10^{-2} \times \pi(0.08)^2 \times \frac{25}{\pi}$
$E_0 = 0.192 \text{ V} \approx 0.19 \text{ V}$
7. **(c)** Motional emf.
$E = Blv$
It depends on magnetic field B, length l, and velocity v, but not on resistance.
• resistance (r)
8. **(c)** Displacement current in charging capacitor.
$I_d = \varepsilon_0 \frac{db_k}{dt}$
9. **(d)** Minimum distance between object and real image for concave mirror occurs when:
$u = v = 2f$
Hence minimum separation:
$u + v = 2f + 2f = 4f$
10. **(c)** Radius of n^{th} orbit in Bohr model:
$r_n \propto n^2$
11. **(d)** Hydrogen atom excitation to $n = 5$
Energy difference between ground state ($n = 1$) and $n = 5$:

$E = 13.6\left(1-\frac{1}{25}\right) = 13.6 \times \frac{24}{25} = 13.06\text{eV}$

Convert to wavelength:

$\lambda = \frac{1240}{E} = \frac{1240}{13.06} \approx 95 \text{ nm}$

12. **(d)** Mass density of a nucleus

Radius relation: $R = R_0A^{1/3}$.

Volume ∝ A.

Mass ∝ A.

So density = Mass/Volume = constant.

• independent of A

13. **(c)**• Output Voltage Across Load Resistor

• Context: A single p-n junction diode connected in series with an AC source and a load resistor acts as a half-wave rectifier.

• Mechanism:

• During the positive half-cycle, the diode is forward-biased and conducts current, producing an output voltage.

• During the negative half-cycle, the diode is reverse-biased and blocks current, resulting in zero output voltage.

• Graph: Graph (c) accurately depicts this intermittent, single-polarity waveform.

14. **(b)**• Doping with Trivalent Impurities

• Mechanism: Trivalent impurities (such as Boron, Aluminum, or Indium) have only 3 valence electrons.

• Effect: When replacing a tetravalent semiconductor atom (like Silicon with 4 valence electrons), a vacancy or hole is created in one of the covalent bonds.

• Result: Holes become the majority charge carriers, making it a p-type (positivetype) semiconductor.

15. **(d)** Energy gap in n-type Si

Donor level lies just below conduction band, typically $\sim 0.01\text{eV}$.

16. **(d)**• Assertion (A): False

• Reason (R): False

Copper is a diamagnetic substance, not paramagnetic. Magnetic field lines do not get concentrated inside it.

So, Both A and R are false.

17. **(a)**• Assertion (A): True

• Reason (R): True

A wavefront is the locus of points vibrating in the same phase, so phase difference is zero.

So, Both A and R are true, and R is the correct explanation of A .

18. **(b)**• Assertion (A): True

• Reason (R): True

Photoelectric effect proves particle nature because emission depends on photons transferring energy individually.

Also, photoelectric current is proportional to intensity when frequency is above threshold.

• But this statement does not explain particle nature directly.

So, Both A and R are true, but R is not the correct explanation of A.

19. Acceleration of the Alpha Particle

The acceleration of a charged particle moving through a magnetic field is calculated using the Lorentz magnetic force formula:

$\vec{F} = q(\vec{v} \times \vec{B}) \Longrightarrow \vec{a} = \frac{\vec{F}}{m} = \left(\frac{q}{m}\right)(\vec{v} \times \vec{B})$

Step 1: Compute the Vector Cross Product $(\vec{v} \times \vec{B})$

Given values:

• $\vec{v} = (3.0 \times 10^5)\hat{\imath}\ \text{m/s}$

• $\vec{B} = 0.4\hat{\imath} + 0.3\hat{\jmath}\ \text{T}$

Using unit vector cross product rules ($\hat{\imath} \times \hat{\imath} = 0$ and $\hat{\imath} \times \hat{\jmath} = \hat{k}$) :

$\vec{v} \times \vec{B} = (3.0 \times 10^5\hat{\imath}) \times (0.4\hat{\imath} + 0.3\hat{\jmath})$

$\vec{v} \times \vec{B} = 0 + (3.0 \times 10^5 \times 0.3)\hat{k} = 9.0 \times 10^4\hat{k}\ \text{T} \cdot\ \text{m/s}$

Step 2: Calculate Acceleration (a)

Substitute the given charge-to-mass ratio ($\frac{q}{m} = 4.8 \times 10^7\text{C/kg}$):

$\vec{a} = (4.8 \times 10^7\text{C/kg}) \times (9.0 \times 10^4\hat{k})$

$\vec{a} = 4.32 \times 10^{12}\hat{k}\ m/s^2$

20. Observability of Induced Fields

An induced electric field due to a changing magnetic field is far more easily observed in standard practice.

• Justification:

• The Factor of $1/c^2$: According to Maxwell's equations, the induced magnetic field created by a changing electric field is scaled by the factor $\mu_0 \xi_0 = \frac{1}{c^2}$. Because the speed of light $c \approx 3 \times 10^8\ m/s$ is massive, $\frac{1}{c^2} \approx 1.11 \times 10^{-17}$ is incredibly small.

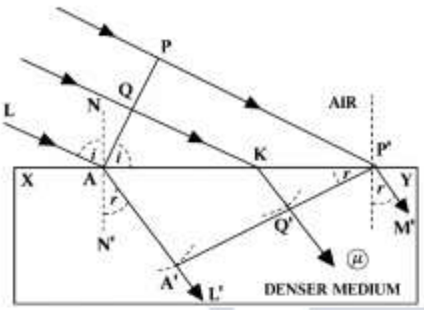
• Detection Threshold: Because of this tiny constant, an exceptionally large, practically unachievable rate of change of electric flux is needed to generate a tiny, measurable magnetic field. Conversely, a changing magnetic field readily creates measurable electromotive force (EMF) and currents that are easily detected using standard laboratory instruments like modern galvanometers.

21. **(A)** Huygens' Principle:

• Each point on the primary wave front acts as a source of secondary wavelets, sending out disturbance in all directions in a similar manner as the original source of light does.

• The new position of the wave front at any instant (called secondary wave front) is the envelope of the secondary wavelets at that instant.

Refraction On The Basis Of Wave Theory



• Consider any point Q on the incident wave front.

• Suppose when disturbance from point P on incident wave front reaches point P ' on the refracted wave front, the disturbance from point Q reaches Q′ on the refracting surface XY.

• Since P′A′ epresents the refracted wave front, the time taken by light to travel from a point on incident wave front to the corresponding point on refracted wave front should always be the same. Now, time taken by light to go from Q to Q will be $t = \frac{QK}{c} + \frac{KQ}{v}$ ... (i)

In right-angled $\triangle$ AQK, $\angle QAK = i$

$\therefore QK = AK\sin i \quad \ldots(ii)$

In right-angled $\triangle P'Q'K, \angle Q'P'K, = r$ and $KQ = KP \sin r \quad \ldots.()$

Substituting (2) and (3) in equation (1),

$$t = \frac{AK\sin i}{c} + \frac{KP'\sin \tau}{v}$$

Or, $\frac{AK\sin i}{c} + \frac{(AP'-AK)\sin r}{v} (\because KP' = AP' - AK)$

Or, $t = \frac{AP'}{c}\sin r + AK\left(\frac{\sin i}{c} - \frac{\sin r}{v}\right) \quad \ldots.(iv)$

The rays from different points on the incident wave front will take the same time to reach the corresponding points on the refracted wave front i.e., t given by equation (iv) is independent of AK. It will happen so, if $\frac{\sin i}{c} - \frac{\sin r}{v} = 0 \Rightarrow \frac{\sin i}{\sin r} = \frac{c}{v} \Rightarrow \mu = \frac{\sin i}{\sin r}$

This is the Snell's law for refraction of light.

OR

(B) The reflecting telescopes are preferred over the refracting type because of the following reasons:

(i) There is no chromatic aberration in the case of reflecting telescopes, as the objective is a mirror.

(ii) Spherical aberration is reduced in the case of reflecting telescopes by using a mirror objective in the form of a paraboloid.

22. Resultant intensity:

$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

Maximum intensity:

$I_{max} = I_1 + I_2 + 2\sqrt{I_1 I_2}$
$= I + 4I + 2\sqrt{4I^2}$
$= 5I + 4I = 9I$
Minimum intensity:
$I_{min} = I_1 + I_2 - 2\sqrt{I_1 I_2}$
$= 5I - 4I = I$
Hence,
$I_{max}: I_{min} = 9:1$

23. Third excited state means:
$n = 4$
Energy of electron:
$$E_n = -\frac{13,6}{n^2}\,eV$$
$$E_4 = -\frac{13.6}{16} = -0.85eV$$
For hydrogen atom:
$K.E. \ = -E_n$
$P.E. \ = 2E_n$
Therefore,
$K.E. = 0.85eV$
$P.E. = -1.7eV$

24. **(A)** Difference between intrinsic and extrinsic semiconductors

Intrinsic Semiconductor	Extrinsic Semiconductor
Pure semiconductor	Doped semiconductor
No impurity atoms	Contains impurity atoms
Electron and hole concentrations are equal	One type of carrier dominates
Low conductivity	Higher conductivity
Example: pure Si, Ge	Example: p-type or n-type Si

OR

(B)

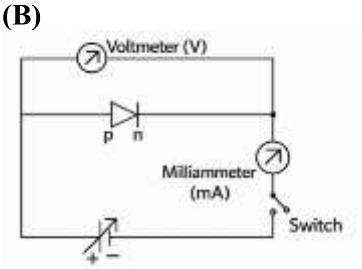


Fig-(a)

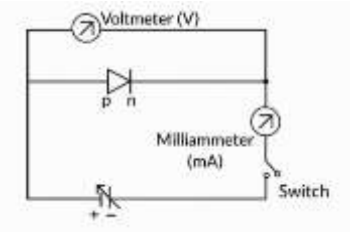


Fig-(b)

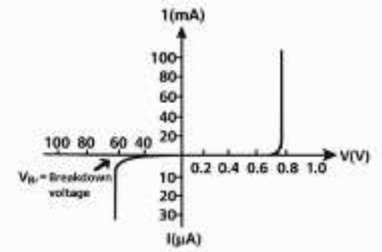


Fig-(c)

• Figures (a) and (b) depict the circuit for examining a diode's V-I properties. The value of current is noted for various voltage values. The result is a graph between C and I, as shown in Fig. (c).

It is evident from a junction diode's V-I characteristics that current can only flow through it when it is forward biassed. As a result, when alternating voltage is placed across a forward biassed diode, current only flows during a portion of the cycle.

• A lternating voltages are rectified using this characteristic.

25. In a p-n junction, due to concentration difference:

• Electrons diffuse from n-side to p-side.

• Holes diffuse from p-side to n-side.

This movement of charge carriers constitutes diffusion current.

Near the junction, electrons and holes recombine and leave behind immobile ions:

• positive ions on n-side

• negative ions on p-side

These ions create an electric field across the junction.

This field opposes further diffusion and produces drift current.

The drift current flows opposite to diffusion current.

Equilibrium is reached when:

Drift current = Diffusion current

As a result, a depletion region and a potential barrier are formed across the junction.

26. Electrostatics

(A) Twelve negative charges on a circle

• Electric Potential (V) : Potential is a scalar quantity. If each charge is $-q$ and they are all at a distance R from the center C, the total potential is the sum of individual potentials:

$$V=\sum \frac{1}{4\pi\epsilon_0}\frac{-q}{R}=12\times\left(-\frac{q}{4\pi\epsilon_0 R}\right)=-\frac{3q}{\pi\epsilon_0 R}$$

• Electric Field ($\vec{E}$): Electric field is a vector quantity. Since the 12 charges are equally spaced around the circle, every charge has an identical charge diametrically opposite to it. The field vectors from these pairs cancel each other out.

$\vec{E}_{net}=0$

(B) Charges on a 120° arc

• Electric Potential (V) : Even if the charges are unequally spaced, they are all at the same distance R from the center C. Since potential is a scalar, the distribution doesn't matter, only the total charge.

$$V=\sum \frac{k(-q)}{R}=-\frac{12q}{4\pi\epsilon_0 R}=-\frac{3q}{\pi\epsilon_0 R}$$

27. **(A)** Resistance vs. Impedance and LCR Expression

• Difference: Resistance (R) is the opposition to current flow offered by a resistor. Impedance (Z) is the total effective opposition offered by a combination of resistance, inductive reactance (X_L), and capacitive reactance (X_C) in an AC circuit.

• Impedance Expression: In a series LCR circuit, the voltages across the components are $V_R = IR, V_L = IX_L$ and $V_C = IX_C$. Using a phasor diagram, the net voltage V_m is:

$$V_m = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$V_m = \sqrt{(IR)^2 + (IX_L - IX_C)^2} = I\sqrt{R^2 + (X_L - X_C)^2}$$

The impedance is $Z = \frac{V_m}{I}$, so:

$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

OR

(B) Resonance in Series LCR

• Condition for Resonance: Resonance occurs when the inductive reactance equals the capacitive reactance:

$$x_L = x_C \Longrightarrow \omega L = \frac{1}{\omega C}$$

• Resonant Frequency: Solving for ω :

$$\omega_r = \frac{1}{\sqrt{LC}} \text{ or } f_r = \frac{1}{2\pi\sqrt{LC}}$$

It depends on the Inductance (L) and Capacitance (C).

• Current vs. Frequency Graph: The graph is a bell-shaped curve peaking at f_r. At resonance, impedance is minimum $(Z = R)$ and current I is maximum.

28. Magnetic field inside a long solenoid:

$B = \mu_0 nI$

Given:

$I = I_0 \sin\omega t$

So, $B = \mu_0 n I_0 \sin\omega t$

Magnetic flux linked with coil:

$\phi = NBA$

where

$A = \pi r^2$

Hence, $\phi = N(\mu_0 n I_0 \sin\omega t)\pi r^2$

(A) Induced emf

Using Faraday's law:

$$\varepsilon = -\frac{d\phi}{dt}$$

$e = -N\mu_0 n\pi r^2 I_0 \omega \cos\omega t$

$e = -\mu_0 nN\pi r^2 \omega I_0 \cos\omega t$

Maximum emf:

$e_0 = \mu_0 nN\pi r^2 \omega I_0$

(B) Mutual inductance

$\phi = MI$

Comparing.

$M = \mu_0 nN\pi r^2$

$M = \mu_0 nN\pi r^2$

29. Einstein's Photoelectric Equation

Einstein's equation: $hv = \Phi_0 + K_{max}$

Where hv is the energy of the incident photon, Φ_0 is the work function (minimum energy to escape), and K_{max} is the maximum kinetic energy of the emitted electron [7, 8].

Explanation:

• Energy Transfer: A single photon transfers its entire energy to a single electron [8, 9].

• Threshold Frequency: Emission only occurs if the photon energy hv is greater than Φ_0. If $v < v_0$, no electrons are ejected, regardless of intensity [8, 9].

• Intensity: Higher intensity means more photons per second, leading to more ejected electrons (higher photocurrent), but doesn't change their individual energy [6, 10].

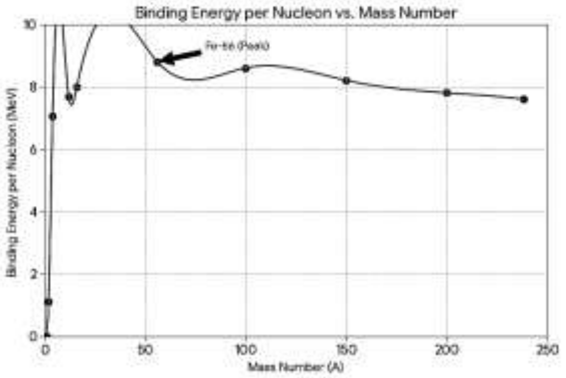
Variation Plots:

(A) Photocurrent vs. Collector Plate Potential

For different intensities (I_1, I_2, I_3) at a constant frequency:
• The curves all start from the same stopping potential (V_0) on the negative voltage axis.
• The saturation current is higher for higher intensities ($I_3 > I_2 > I_1$)[6,10].
(B) Photocurrent vs. Intensity of Incident Radiation
• This is a straight line passing through the origin, showing that photocurrent is directly proportional to the intensity of incident light [6,10].

30. (A) Energy Level Diagram for Hydrogen Atom

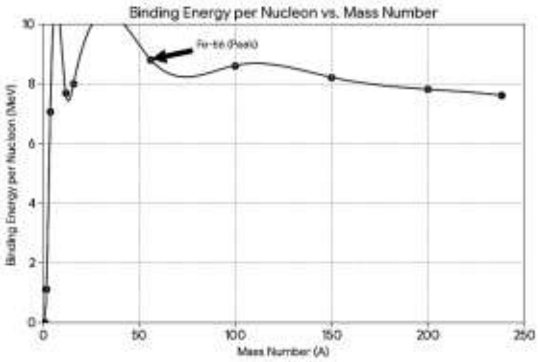
The energy levels (E_n) of a hydrogen atom are quantized and given by the formula $E_n = -\frac{13.6}{n^2}$ eV, where n is the principal quantum number.



Transitions and Spectral Regions
• Ultraviolet Region (Lyman Series): Transitions from higher energy levels ($n = 2,3,4,\ldots$) down to the ground state ($n = 1$).
• Visible Region (Balmer Series): Transitions from higher energy levels ($n = 3,4,5,\ldots$) down to the first excited state ($n = 2$).
• Infrared Region: Includes several series:
• Paschen Series: Transitions to $n = 3$.
• Brackett Series: Transitions to $n = 4$.
• Pfund Series: Transitions to $n = 5$.

OR

(B) Binding Energy per Nucleon Curve
The binding energy per nucleon (BE/A) indicates the stability of a nucleus.



Salient Features of the Curve
(1) Peak Stability: The curve reaches a maximum value of approximately 8.8 MeV for Iron (^{56}Fe), indicating it is the most stable nucleus.
(2) Constancy for Intermediate Nuclei: For nuclei with mass numbers between $30 < A < 170$, the binding energy per nucleon is nearly constant at about 8.5 MeV .
(3) Low BE for Light and Heavy Nuclei: Both very light nuclei ($A < 20$) and very heavy nuclei ($A > 170$) have lower binding energy per nucleon, making them less stable.
• Why Lighter Nuclei Undergo Nuclear Fusion
Lighter nuclei have a lower binding energy per nucleon. By combining (fusing) to form a heavier, more stable nucleus (closer to the peak at Iron), the total binding energy per nucleon increases. This transition from a less stable to a more stable state releases a massive amount of energy, as the final mass is less than the initial mass of the individual nuclei.

31. (A)(i) Coulomb's law

The electrostatic force between two point charges is:

• directly proportional to the product of charges

• inversely proportional to the square of distance between them

• acts along the line joining the charges.

Magnitude:

$$F=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$$

Vector form:

$$\vec{F}_{12}=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}\hat{r}_{12}$$

where $\hat{r}_{12}$ is the unit vector from charge q_1 to q_2.

(ii) Relation between Gauss's law and inverse-square law

According to Coulomb's law:

$$E\propto\frac{1}{r^2}$$

For a point charge enclosed by a spherical surface of radius r :

Surface area of sphere:

$$A=4\pi r^2$$

Total electric flux:

$$\Phi=E\times4\pi r^2$$

Since $E\propto1/r^2$,

$$\Phi=\text{ constant}$$

Thus electric flux through a closed surface depends only on enclosed charge and not on size of surface, which is Gauss's law.

(iii) Force Exerted by A on B

(1) Identify Charges and Positions

• Charge A: $q_A=q$ at position $\vec{r}_A=0\hat{i}+0\hat{j}$.

• Charge B: $q_B=2q$ at position $\vec{r}_B=a\hat{i}+a\hat{j}$.

(2) Calculate the Displacement Vector and Distance The displacement vector $\vec{r}_{AB}$ from A to B is:

$$\vec{r}_{AB}=\vec{r}_B-\vec{r}_A=a\hat{i}+a\hat{j}$$

The distance r is the magnitude of this vector:

$$r=\sqrt{a^2+a^2}=\sqrt{2a^2}=a\sqrt{2}$$

(3) Determine the Unit Vector

The unit vector $\hat{r}_{AB}$ in the direction of the force is:

$$\hat{r}_{AB}=\frac{\vec{r}_{AB}}{r}=\frac{a\hat{i}+a\hat{j}}{a\sqrt{2}}=\frac{1}{\sqrt{2}}\hat{i}+\frac{1}{\sqrt{2}}\hat{j}$$

(4) Apply Coulomb's Law

$$\vec{F}_{AB}=\frac{1}{4\pi\varepsilon_0}\frac{q_Aq_B}{r^2}\hat{r}_{AB}$$

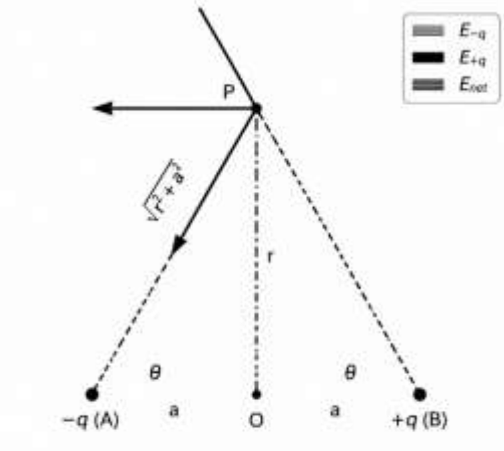
$$\vec{F}_{AB}=\frac{1}{4\pi\varepsilon_0}\frac{(q)(2q)}{(a\sqrt{2})^2}\left(\frac{1}{\sqrt{2}}\hat{i}+\frac{1}{\sqrt{2}}\hat{j}\right)$$

$$\vec{F}_{AB}=\frac{1}{4\pi\varepsilon_0}\frac{2q^2}{2a^2}\left(\frac{1}{\sqrt{2}}\hat{i}+\frac{1}{\sqrt{2}}\hat{j}\right)$$

$$\vec{F}_{AB}=\frac{1}{4\pi\varepsilon_0}\frac{q^2}{a^2}\left(\frac{1}{\sqrt{2}}\hat{i}+\frac{1}{\sqrt{2}}\hat{j}\right)$$

OR

(B) (i) Derivation of Electric Field on the Equatorial Plane of a Dipole



Consider an electric dipole consisting of charges $-q$ at point A and $+q$ at point B. separated by a distance 2a. Let P be a point on the equatorial line at a distance r from the center O.

The distance of point P from both charges is:

$AP = BP = \sqrt{r^2 + a^2}$

(1) Electric field due to $+q$ at P.

$$E_{+q} = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2+a^2)} \text{ (directed away from B)}$$

(2) Electric field due to $-q$ at P.

$$E_{-q} = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2+a^2)} \text{ (directed towards A)}$$

The magnitudes are equal: $E_{+q} = E_{-q}$. Resolving the fields into components:

• The normal components ($E_{+q}\sin\theta$ and $E_{-q}\sin\theta$) are equal and opposite, so they cancel out.

• The parallel components ($E_{+q}\cos\theta$ and $E_{-q}\cos\theta$) act in the same direction (opposite to the dipole moment vector $\vec{p}$) and add up.

$E_{net} = E_{+q}\cos\theta + E_{-q}\cos\theta = 2E_{+q}\cos\theta$

From $\triangle$ POB, $\cos\theta = \frac{a}{\sqrt{r^2+a^2}}$. Substituting this into the equation:

$$E_{net} = 2\left[\frac{1}{4\pi\varepsilon_0}\frac{q}{(r^2+a^2)}\right]\frac{a}{(r^2+a^2)^{1/2}}$$

$$E_{net} = \frac{1}{4\pi\varepsilon_0}\frac{q(2a)}{(r^2+a^2)^{3/2}}$$

Since the dipole moment is $p = q(2a)$:

$$E_{net} = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2+a^2)^{3/2}}$$

For a short dipole ($r \gg a$):

$$E_{net} \approx \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

(ii) Effect of halving distance

For far-off point ($r \gg a$):

$$E \approx \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{r^3}$$

If $r \to \frac{r}{2}$:

$$E' = \frac{p}{(r/2)^3} = 8 \cdot \frac{p}{r^3} = 8E$$

Electric field increases 8 times.

(iii) Two identical dipoles along diagonals of square

Square side $= \sqrt{2}$ m.

Centre O is equidistant from all corners.

Dipoles placed along diagonals AC and BD.

• Each dipole produces field at O along its axis.

• By symmetry, the two fields are perpendicular (one along AC, one along BD).

• Magnitudes are equal: say E.
• Net field at O :
$E_{net} = \sqrt{E^2 + E^2} = \sqrt{2}E$
Direction: along the vector bisecting the angle between AC and BD, i.e. along the line joining centres of opposite sides (say AB or CD).
Net field $= \sqrt{2}E$, directed at 45° between the diagonals.

32. (A) (i) Biot-Savart's Law & Circular Loop Field

(1) Statement of Biot-Savart's Law

The magnetic field $d\vec{B}$ produced at a position vector $\vec{r}$ due to a small current element $I\vec{d}$ is:

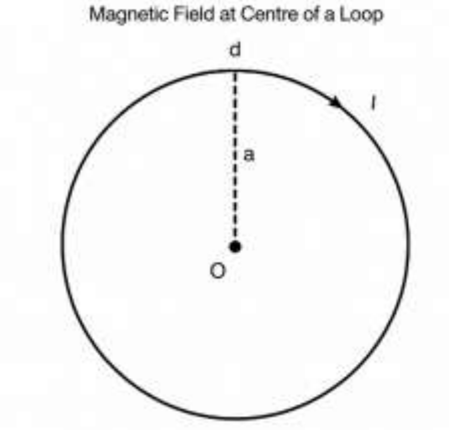
$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l} \times \hat{r})}{r^2}$$

Its magnitude is given by:

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

where θ is the angle between the current element $d\vec{l}$ and the position vector $\vec{r}$.

(2)Magnetic Field at the Centre of a Circular Loop



Consider a circular loop of radius a carrying a steady current I. Let $d\vec{l}$ be a small current element along the boundary. The angle θ between $d\vec{l}$ and the radius vector $\vec{a}$ is always 90° everywhere on the circle.
According to Biot-Savart's Law, the small magnetic field dB at the center O is:

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin 90^\circ}{a^2} = \frac{\mu_0}{4\pi}\frac{Idl}{a^2}$$

Integrating this expression over the full circumference of the loop to get the total field B :

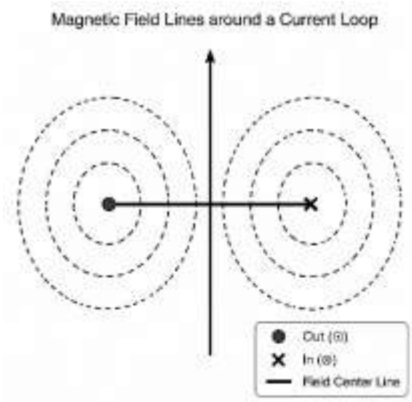
$$B = \int dB = \frac{\mu_0 I}{4\pi a^2}\int dl$$

Since $\int dl = 2\pi a$ (total circumference):

$$B = \frac{\mu_0 I}{4\pi a^2}\cdot(2\pi a)$$

$$B = \frac{\mu_0 I}{2a}$$

(3) Field Lines Diagram



• Direction Rule: Determined by the Right-Hand Thumb Rule. Curl the fingers of your right hand in the direction of the current, and your extended thumb points in the direction of the internal magnetic field lines.

(ii) Current Constituted by Revolving Electron

(1) Given Parameters:

• Electron speed $(v) = 10^{7}\ m/s$

• Orbit radius $(r) = 10^{-10}\ m$

• Electron charge $(e) = 1.6 \times 10^{-19} C$

(2) Time Period of One Revolution (T):

$$T = \frac{2\pi r}{v}$$

(3) Electric Current Formula (N):

$$I = \frac{e}{T} = \frac{ev}{2\pi r}$$

$$I = \frac{(1.6 \times 10^{-19} C) \times (10^{7}\ m/s)}{2 \times 3.14 \times 10^{-10}\ m}$$

$$I = \frac{1.6 \times 10^{-12}}{6.28 \times 10^{-10}} \approx 2.55 \times 10^{-3}\ A$$

$$I \approx 2.55\ mA$$

OR

(B) (i) Force on Straight Conductor in Magnetic Field

(1) Derivation

Consider a straight conductor of length I, uniform cross-sectional area A, carrying a current I. Let it be placed in a uniform external magnetic field $\vec{B}$.

• Let n be the number density of free electrons.

• Let $\vec{v}_d$ be the drift velocity of these electrons.

• Total number of free electrons in the wire $= n \cdot A \cdot I$

The magnetic Lorentz force on a single moving electron with charge - e is:

$$\vec{f} = -e(\vec{v}_d \times \vec{B})$$

The total force $\vec{F}$ acting on all free electrons within the conductor is:

$$\vec{F} = (nAl) \cdot \vec{f} = nAl[-e(\vec{v}_d \times \vec{B})]$$

$$\vec{F} = (nAev_d) \cdot (-l\hat{v}_d \times \vec{B})$$

Since current $I = nAev_d$, we define a length vector $\vec{l}$ pointing in the conventional current direction (opposite to electron drift velocity $\vec{v}_d$):

$$\vec{F} = I(\vec{l} \times \vec{B})$$

In magnitude form:

$$F = IlB\sin\theta$$

where θ is the angle between the length of the conductor and the magnetic field vector.

(2) Direction Rule

Fleming's Left-Hand Rule: Stretch the thumb, forefinger, and middle finger of your left hand mutually perpendicular to each other. If the Forefinger points in the direction of the Magnetic Field and the Central finger points in the direction of the Current, then the Thumb points in the direction of the mechanical Motion/Force.

(3) Conditions

(1) Maximum Force ($\theta = 90^\circ$) : Occurs when the conductor is held perpendicular to the magnetic field line directions ($F_{max} = IB$).
(2) Minimum Force ($\theta = 0^\circ$ or 180°) : Occurs when the conductor is kept parallel or anti-parallel to the magnetic field lines ($F_{min} = 0$).
(ii) Force Exerted Between Parallel Wires
(1) Given Parameters:
• Current in wire $A(I_1) = 5.0$ A
• Current in wire $B(I_2) = 2.5$ A
• Separation distance $(d) = 2.5$ cm $= 0.025$ m
• Length segment of wire $B(L) = 10$ cm $= 0.1$ m
(2) Force Formula per Unit Length:

$$f = \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

(3) Total Force on Length L :

$$F = \left(\frac{\mu_0}{4\pi}\right)\frac{2I_1I_2L}{d}$$

$$F = (10^{-7}) \times \frac{2 \times 5.0 \times 2.5 \times 0.1}{0.025}$$

$$F = 10^{-7} \times \frac{2.5}{0.025} = 10^{-7} \times 100$$

$$F = 1.0 \times 10^{-5}\ \mathrm{N}$$

33. (A) (i) (a) The interference pattern has a number of equally spaced bright and dark bands. The diffraction pattern has a central bright maximum which is twice as wide as the other maxima. The intensity falls as we go to successive maxima away from the centre, on either side.
(b) We calculate the interference pattern by superposing two waves originating from the two narrow slits. The diffraction pattern is a superposition of a continuous family of waves originating from each point on a single slit.
(2) Factors affecting fringe width
The fringe width (β) in Young's double-slit experiment is given by the formula $\beta = \frac{AD}{d}$.
Based on this, two key factors it depends on are
• Wavelength of light ($\boldsymbol{\lambda}$): The fringe width is directly proportional to the wavelength. Using light with a longer wavelength (like red) results in wider fringes.
• Distance between the two slits (d): The fringe width is inversely proportional to the separation between the slits. Bringing the slits closer together increases the width of the fringes.
(Note: It also depends on the distance between the slits and the screen, D
(ii) Data: $d = 100\lambda, D = 50.0$ cm
The conditions for maximum in Young's experiment is given by:
$d\sin(\theta) = n\lambda, n = 0,1,2 \ldots$
the angle between the central maximum and it's adjacent can be determined by setting m equals to 1 , so:

$$d\sin(\theta) = \lambda$$

$$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right)$$

$$\theta = \sin^{-1}\left(\frac{\lambda}{100\lambda}\right)$$

$$\theta = \sin^{-1}\left(\frac{1}{100}\right)$$

$$\theta = 0.01\mathrm{rad}$$

The distance between the central axis and the first maximum is given by:

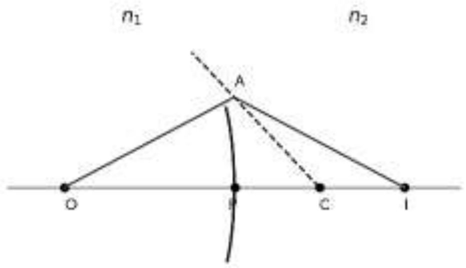
$$D\sin\theta = D\left(\frac{\lambda}{d}\right)$$

$$= (50.0\ \mathrm{cm})\left(\frac{\lambda}{100\lambda}\right)$$

$$= 0.50\ \mathrm{cm}$$

OR

(B) (i) Derivation of Refraction at a Spherical Surface



Let a convex spherical surface of radius of curvature R separate a rarer medium of refractive index n_1 from a denser medium of refractive index n_2. Let P be the pole, and C be the center of curvature. A point object O is kept on the principal axis in medium n_1

An incident ray OA strikes the interface at point A and bends toward the normal AN (since $n_2 > n_1$), meeting the principal axis at point I, which forms a real image.

Let the angles made by the incident ray, normal, and refracted ray with the principal axis be α, γ and β respectively:

- $\angle AOP = \alpha$
- $\angle AIP = \beta$
- $\angle ACP = \gamma$

From exterior angle properties in $\triangle$ OAC and $\triangle$ IAC :

(1) Angle of incidence: $i = \alpha + \gamma$

(2) Angle of curvature: $\gamma = r + \beta \Longrightarrow r = \gamma - \beta$

According to Snell's Law:

$n_1 \sin i = n_2 \sin r$

For paraxial rays, the angles i and r are very small, so $\sin i \approx i$ and $\sin r \approx r$. Thus:

$n_1 i = n_2 r$

Substituting the expressions for i and r :

$n_1(\alpha + \gamma) = n_2(\gamma - \beta)$

$n_1\alpha + n_2\beta = (n_2 - n_1)\gamma$ ....(i)

Since the aperture is small, the angles can be approximated by their tangents ($\alpha \approx \tan\alpha$, $\beta \approx \tan\beta, \gamma \approx \tan\gamma$).

Dropping a perpendicular from A to the principal axis at point M (where $M \approx P$):

$$\alpha \approx \frac{AM}{PO}, \beta \approx \frac{AM}{PI}, \gamma \approx \frac{AM}{PC}$$

Substituting these into Equation 1:

$$n_1\left(\frac{AM}{PO}\right) + n_2\left(\frac{AM}{PI}\right) = (n_2 - n_1)\left(\frac{AM}{PC}\right)$$

$$\frac{n_1}{PO} + \frac{n_2}{PI} = \frac{n_2 - n_1}{PC}$$

Applying the Cartesian sign convention:

- Object distance: $PO = -u$
- Image distance: $PI = +v$
- Radius of curvature: $PC = +R$

$$\frac{n_1}{-u} + \frac{n_2}{v} = \frac{n_2 - n_1}{R}$$

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

(ii) Numerical Problem: Apparent Position of the Bubble

(1) Identification of Parameters

Light travels from the bubble inside the glass sphere out to the observer's eye E in the air.

- Refractive index of first medium (Glass): $n_1 = 1.5$
- Refractive index of second medium (Air): $n_2 = 1.0$
- Radius of curvature (R): Since the boundary curved surface is concave toward the direction of outgoing light, its center lies inside the glass against the direction of ray propagation. Thus, $R = -6.0$ cm.
- Object Distance (u) : The bubble is 3.0 cm from the center C. Since the radius is 6.0 cm , its actual depth from the nearest viewing surface boundary is $6.0 - 3.0 = 3.0$ cm. Measuring against the direction of incident light gives $u = -3.0$ cm.

(2) Calculation
Using the spherical refraction formula derived above:
$$\frac{n_2}{v}-\frac{n_1}{u}=\frac{n_2-n_1}{R}$$
Substitute the values:
$$\frac{1.0}{v}-\frac{1.5}{-3.0}=\frac{1.0-1.5}{-6.0}$$
$$\frac{1}{v}+0.5=\frac{-0.5}{-6.0}$$
$$\frac{1}{v}+\frac{1}{2}=\frac{1}{12}$$
$$\frac{1}{v}=\frac{1}{12}-\frac{1}{2}=\frac{1-6}{12}=-\frac{5}{12}$$
$$v=-\frac{12}{5}=-2.4 \text{ cm}$$
Result: The negative sign indicates that a virtual image is formed on the same side as the object. The apparent position of the bubble is 2.4 cm below the surface of the sphere (or 3.6 cm away from the center C).

34. **(A)** Points at the same potential
Since they are connected by ideal wires:
• a, b, c are at the same potential.
• h, g, f are at the same potential.
• d, e are at the same potential.
(B) Current through arm bg
The right branch has:
$R_2+R_3=5+5=10\Omega$
This is in parallel with $R_1=10\Omega$.
Equivalent resistance of parallel combination:
$$R_p=\frac{10\times10}{10+10}=5\Omega$$
Total resistance in circuit:
$R_{total}=R_p+r=5+1=6\Omega$
Total current from battery:
$$I=\frac{E}{R_{total}}=\frac{6}{6}=1A$$
Voltage across parallel combination:
$V=IR_p=1\times5=5V$
Current through arm bg (through R_1):
$$i=\frac{5}{10}=0.5 \text{ A}$$
(C) Potential difference across R_3
Current in right branch:
$$I_{right}=\frac{5}{10}=0.5 \text{ A}$$
Hence voltage across R_3 :
$V_{R_3}=IR_3=0.5\times5=2.5 \text{ V}$

OR

(C) Power dissipated in R_2
$P=I^2R$
$P=(0.5)^2\times5$
$P=0.25\times5=1.25 \text{ W}$

35. **(A)** Path of the Ray through the Prism
(1) First Interface (Face AB): Since the ray is incident normally ($\angle i=0^\circ$), it passes into the prism without deviation.
(2) Second Interface (Face AC): In an equilateral triangle, the angle of incidence at the second face will be 60°.
(i) Critical Angle (i_c): Given as 24.5°.

(ii) Condition Check: Since the angle of incidence (60°) is greater than the critical angle (24.5°), the ray undergoes Total Internal Reflection (TIR).
(3) Exit: The ray reflects off face AC and travels toward face BC, hitting it at a normal angle and exiting the prism without further deviation.

(B) Velocity of Light through the Prism
The velocity of light in a medium (v) is calculated using the refractive index (n) :

$$v = \frac{c}{n}$$

Where:
• $c = 3 \times 10^8$ m/s (speed of light in vacuum)
• $n = 2.41$ (given refractive index)

$$v = \frac{3 \times 10^8}{2.41} \approx 1.24 \times 10^8 \text{ m/s}$$

(C) Total Internal Reflection (TIR)
Definition: The phenomenon where a ray of light traveling from a denser to a rarer medium is reflected back into the denser medium when the angle of incidence is greater than the critical angle.
• Two Conditions for TIR:
(1) Light must travel from an optically denser medium to an optically rarer medium.
(2) The angle of incidence must be greater than the critical angle for the given pair of media.

OR

(C) Two Applications of TIR:
(1) Optical Fibers: Used in telecommunications to transmit signals over long distances with minimal loss.
(2) Brilliance of Diamonds: Light undergoes multiple internal reflections due to a high refractive index and low critical angle, creating a sparkle.

36. **(c)** Electric field due to a point charge

$$E \propto \frac{1}{r^2}$$

Given $E_1 = 9$ N/C at $r_1 = 4$ m,
Find r_2 when $E_2 = 16$ N/C :

$$\frac{E_2}{E_1} = \frac{r_1^2}{r_2^2} = \frac{16}{9} = \frac{16}{r_2^2} \Rightarrow r_2^2 = 9 \Rightarrow r_2 = 3 \text{ m}$$

37. **(a)** Potential on axis of an electric dipole
Potential on axis:

$$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2p}{x^2}$$

So $V \propto \frac{1}{x^2}$.

38. **(b)** Heat produced in conductor

$$H = I^2 Rt$$

Given $l = 0.8$ A, $R = 40\Omega, t = 60$ s:

$$H = (0.8)^2 \times 40 \times 60 = 0.64 \times 2400 = 1536 \text{ J}$$

39. **(d)** Internal resistance of cell

$$E = I(R + r), V = IR$$

$$r = \frac{E - V}{I} = \frac{E - V}{V/R} = \frac{(E - V)R}{V}$$

40. **(a)** Electron and proton beams moving parallel
• Both have opposite charges → electrostatic attraction.
• Currents in same direction → magnetic attraction.
Net effect: they attract each other.

41. **(b)** For a long straight wire:
Inside the wire ($r < a$),

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

At $r = \frac{a}{2}$,

$$B_1=\frac{\mu_0 I(a/2)}{2\pi a^2}=\frac{\mu_0 I}{4\pi a}$$

Outside the wire ($r>a$),

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

At $r=2a$,

$$B_2=\frac{\mu_0 I}{4\pi a}$$

Hence,

$$\frac{B_1}{B_2}=1$$

42. (c) Direction of propagation of EM wave

• In an electromagnetic wave, $\vec{E}, \vec{B}$, and propagation direction are mutually perpendicular.

• Direction of propagation $=\vec{E}\times\vec{B}$.

43. (c) • Reflected vs refracted rays

• Frequency of light remains unchanged during reflection/refraction.

44. (c) Wavelength in air

Speed in medium: $v=1.5\times 10^{B}\mathrm{m/s}$, wavelength in medium: $\lambda_m=230$ nm.

Frequency:

$$f=\frac{v}{\lambda_{\mathrm{m}}}=\frac{1.5\times 10^8}{230\times 10^{-9}}\approx 6.52\times 10^{14}\ \mathrm{Hz}$$

In air ($c=3\times 10^8$) :

$$\lambda_{\text{air}}=\frac{c}{f}\approx\frac{3\times 10^8}{6.52\times 10^{14}}\approx 460\ \mathrm{nm}$$

45. (c) Photoelectric emission with visible light

• Alkali metals (Rb, Na, Cs) have low work function → emit with visible light.

• Cadmium has higher work function → does not emit with visible light.

46. (d) Using Bohr's formula:

$$\frac{1}{\lambda}=R\left(\frac{1}{n_1^2}-\frac{1}{n_2^2}\right)$$

For transition 5 → 1 :

$$\frac{1}{\lambda_1}=R\left(1-\frac{1}{25}\right)=\frac{24R}{25}$$

For transition 5 → 2 :

$$\frac{1}{\lambda_2}=R\left(\frac{1}{4}-\frac{1}{25}\right)=R\left(\frac{21}{100}\right)$$

$$\frac{\lambda_2}{\lambda_1}=\frac{24/25}{21/100}=\frac{32}{7}$$

47. (d) Higher binding energy per nucleon means greater stability.

• more stable nucleus than its neighbours

48. (c) For semiconductor:

$$n_i^2=np$$

Given:

$p=4\times 10^{20}\ \mathrm{m}^{-3}$

$n_i=1.2\times 10^{15}\ \mathrm{m}^{-3}$

$$n=\frac{n_i^2}{p}$$

$$n=\frac{(1.2\times 10^{15})^2}{4\times 10^{27}}=3.6\times 10^9\ \mathrm{m}^{-3}$$

49. (d) With increase in temperature:

• Conductivity of copper decreases.

• Conductivity of silicon increases.

• copper decreases and silicon increases

50. **(b)** Depletion region is formed due to diffusion of electrons and holes across the junction.

51. **(c)** Assertion (A) is true and Reason (R) is false.

Explanation:

Diamagnetic material does not have permanent dipole moment but it can exhibit magnetism. Hence assertion is true and reason is false.

52. **(a)**• Assertion (A) is true.

Work done in moving a charge around a closed path in an electrostatic field is zero.

• Reason (R) is also true.

Electrostatic force is conservative.

• R correctly explains A.

So, Both A and R are true and R is the correct explanation of A .

53. **(a)** In Young's double slit experiment,

$$\beta = \frac{\lambda D}{d}$$

$$\beta = \frac{\lambda D}{d}$$

Since fringe width remains constant for fixed λ, D, and d_r all fringes are equally spaced.

So, Assertion (A) is true.

Reason (R) is also true and correctly explains A.

So, Both A and R are true and R is the correct explanation of A.

54. A galvanometer is a sensitive instrument which can detect only small currents.

To measure large currents, it is converted into an ammeter.

Conversion:

A small resistance called shunt resistance is connected in parallel with the galvanometer.

• Most of the current passes through the shunt.

• Only a small safe current flows through the galvanometer coil.

Hence the combination acts as an ammeter having low resistance.

55. **(A)** Infrared waves

Production of infrared waves:

Infrared waves are produced by hot bodies and vibrating molecules.

Why are they called heat waves?

Because they produce heating effect when absorbed by objects.

Any two uses:

(1) In TV remote controls

(2) In physiotherapy/heating applications

OR

(B) X-rays

Production of X-rays:

X-rays are produced when fast moving electrons strike a heavy metal target of high melting point.

Any two uses:

(1) Detecting bone fractures in medicine

(2) Detecting cracks in metal objects

56. Image formed by combination of lenses

Given:

• Radius of curvature $R = 15$ cm

• Refractive index $\mu = 1.5$

• Separation between lenses $= 20$ cm

Step 1: Focal length of plano-convex lens

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For plano-convex lens:

$R_1 = +15 \text{ cm}, R_2 = \infty$

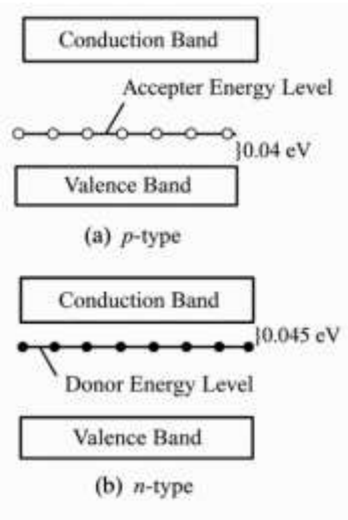
$$\frac{1}{f_1} = (1.5 - 1)\left(\frac{1}{15} - 0\right)$$
$$\frac{1}{f_1} = \frac{1}{30}$$
$f_1 = 30$ cm
So the first lens forms image 30 cm to its right.
Step 2: Object position for second lens
Distance between lenses = 20 cm
Therefore image formed by first lens is:
$30 - 20 = 10$ cm
to the right of second lens.
Hence for second lens:
$u = +10$ cm
(virtual object)
Step 3: Focal length of plano-concave lens
For plano-concave lens:
$R_1 = -15$ cm, $R_2 = \infty$
$$\frac{1}{f_2} = (1.5 - 1)\left(0 - \frac{1}{15}\right)$$
$$\frac{1}{f_2} = -\frac{1}{30}$$
$f_2 = -30$ cm
Step 4: Lens formula
$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$
$$\frac{1}{v} - \frac{1}{10} = -\frac{1}{30}$$
$$\frac{1}{v} = \frac{1}{10} - \frac{1}{30}$$
$$\frac{1}{v} = \frac{1}{15}$$
$v = 15$ cm

57. The fringe width (β) in an interference pattern is given by the formula:
$$\beta = \frac{\lambda D}{d}$$
(where λ is wavelength, D is the distance to the screen, and d is the distance between the two coherent sources)
(A) When sources are infinitely close ($d \to 0$):
As d becomes extremely small, the fringe width β becomes infinitely large $\left(\beta \propto \frac{1}{d}\right)$. Because a single fringe spreads out to cover the entire field of view, no distinct interference pattern (fringes) will be visible; instead, a broad, uniform illumination will be observed on the screen.
(B) When sources are far apart from each other (d is very large):
As d increases significantly, the fringe width β becomes extremely small. The interference fringes become so closely packed together that the resolving power of the human eye (or standard instruments) cannot tell them apart. Consequently, the fringes overlap and blur together, resulting in a continuous uniform illumination on the screen where the individual dark and bright bands are completely lost.

58. **(A)** The energy needed to transfer an electron from its ground state energy level to its free state is known as the ionisation energy of an atom. The ionisation energy measures an element's ability to participate in chemical processes that call for the creation of ions or the donation of electrons.
• A hydrogen Atom's ionisation energy is 13.6 eV
OR
(B) Definition: The difference between the sum of masses of individual nucleons and the actual mass of the nucleus.
$\Delta m = \left(Zm_p + (A - Z)m_n\right) - m_{\text{nucleus}}$
• Relation to stability: Larger mass defect → higher binding energy → more stable nucleus.

Mass defect is directly linked to nuclear stability.

59.



60. (i) A strong current damages a p-n junction diode because it increases the semiconductor's temperature as more power passes through it and some of that energy is converted to heat. The semiconductor then conducts more current as the temperature rises a little further, which raises the temperature even further. Higher temperature results in more current, which increases the temperature. In what is referred to as a thermal runaway, this cycle keeps repeating. The semiconductor (p-n junction) is ultimately destroyed.

(ii) To improve a semiconductor's electrical conductivity, impurities are added. Doping is the process of introducing impurities into semiconductors to improve their electrical conductivity; these impurities are referred to as intrinsic semiconductors.

61. (A) Let a be the radius of a sphere A, Q_A be the charge on the sphere and C_A be the capacitance of that sphere. Let b be the radius of a sphere B, Q_B be the charge on the sphere, and C_B be the capacitance of that sphere. Since the two spheres are connected by a wire, their potentia (V) will become equal. Let E_A be the electric field of sphere A and E_B by the electric field of sphere B. Then,

$$\frac{E_A}{E_B}=\left(\frac{Q_A}{4\pi\varepsilon_0 a^2}\right)\times\left(\frac{b^2 4\pi\varepsilon_0}{Q_B}\right)$$

$$\frac{E_A}{E_B}=\frac{Q_A}{Q_B}\times\frac{b^2}{a^2} \quad \ldots(i)$$

However, $\frac{Q_A}{Q_B}=\frac{C_A V}{C_B V}$ .....(ii)

and $\frac{C_A}{C_B}=\frac{a}{b}$ .....(iii)

Putting the values of (ii) and (iii) in (i), we get,

$$\frac{E_A}{E_B}=\frac{b}{a}$$

Therefore, the required ratio of electric fields at the surface of the spheres is $\frac{b}{a}$.

OR

(B) Capacitors

(i) Ratio of final charges:

When capacitor $A(C)$ is connected to uncharged capacitor $B(2C)$, they share the initial charge $Q_0=CV$ until they reach a common potential $V'=\frac{Q_0}{C_A+C_B}=\frac{CV}{3C}=\frac{V}{3}$

• Charge on A: $Q_A=C\cdot V'=\frac{CV}{3}$

• Charge on B: $Q_B=2C\cdot V'=\frac{2CV}{3}$

Ratio $Q_A:Q_B=1:2$ e

(ii) Ratio of energies:

• Initial energy (U_i): $\frac{1}{2}CV^2$

• Final energy (U_f): $\frac{1}{2}(C+2C)(V')^2=\frac{1}{2}(3C)\left(\frac{V}{3}\right)^2=\frac{1}{6}CV^2$

Ratio $U_f:U_t=\frac{1/6}{1/2}=1:3$

62. Definitions and Resistivity

• Current Density (J): The amount of electric current flowing per unit cross-sectional area of a conductor ($J=IA$). It is a vector quantity.

• Relaxation Time (τ): The average time interval between two successive collisions of an electron with the positive ions in a conductor.

Derivation:

(1) Drift velocity $v_d=\frac{cEr}{m}$

(2) Current $I=neAv_d \Longrightarrow I=neA\left(\frac{eEr}{m}\right)=\frac{ne^2Ar}{m}E$

(3) Since $E=VII$, then $I=\frac{m^2Ar}{ml}V \Longrightarrow V=I\left(\frac{m}{me^2r}\right)\frac{I}{A}$

(4) Comparing with Ohm's Law ($V=IR$ and $R=\rho\frac{I}{A}$):

$$\rho=\frac{m}{ne^2\tau}$$

63. CR Circuit Calculation

Given: $R=200\Omega, C=\frac{50}{\pi}\mu F, \varepsilon_0=100V, f=50Hz.$

• Capacitive Reactance (X_C) :

$$X_C=\frac{1}{2\pi fC}=\frac{1}{2\pi(50)\left(\frac{50}{\pi}\times10^{-6}\right)}=\frac{1}{5000\times10^{-6}}=200\Omega$$

(a) Impedance (Z):

$$Z=\sqrt{R^2+X_C^2}=\sqrt{200^2+200^2}=200\sqrt{2}\approx282.8\Omega$$

(b) Phase angle (ϕ) :

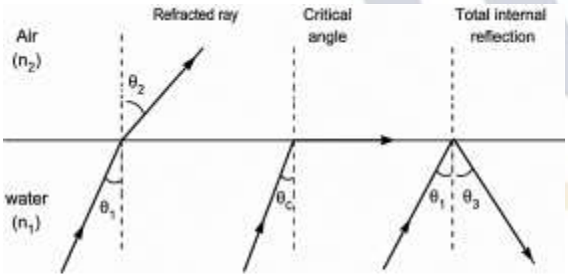
$$\tan\phi=\frac{x_C}{R}=\frac{200}{200}=1\Longrightarrow\phi=45^\circ(\text{ or }\pi/4\text{rad})$$

(c) Voltage across Resistor (V_R):

Peak current $I_0=\frac{\varepsilon_0}{Z}=\frac{100}{200\sqrt{2}}=\frac{1}{2\sqrt{2}}A$

Peak voltage $V_R=I_0R=\left(\frac{1}{2\sqrt{2}}\right)(200)=\frac{100}{\sqrt{2}}=50\sqrt{2}\approx70.7V$

64. Critical angle and total internal reflection



• Critical angle: The angle of incidence in the denser medium for which the angle of refraction in the rarer medium becomes 90°.

• Total internal reflection (TIR): When light travels from a denser to a rarer medium and the angle of incidence exceeds the critical angle, the light is completely reflected back into the denser medium.

Derivation:

From Snell's law:

$n_1\sin i=n_2\sin r$

At the critical angle $C, r=90^\circ$:

$n_1\sin C=n_2\sin90^\circ=n_2$

$\sin C=\frac{n_2}{n_1}$

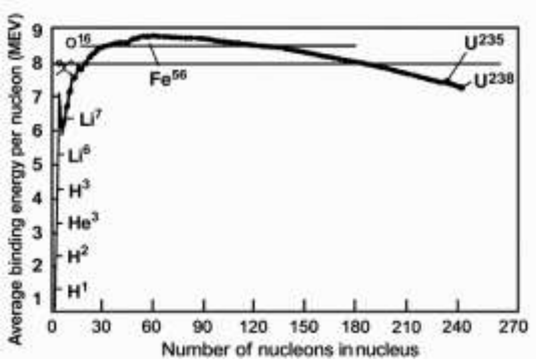
If $n_1=n$ (denser medium) and $n_2=1$ (air):

$\sin C = \frac{1}{n}$

65. (i)

Nuclear Fission	Nuclear Fusion
Nuclear fission is the process by which an atom's nucleus breaks into two lighter nuclei during a nuclear reaction.	In the process of nuclear fusion, two or more light nuclei collide to create a heavier nucleus.
An enormous quantity of energy is produced when each atom divides.	Compared to nuclear fission, nuclear fusion produces energy that is several times more powerful.
Natural fission reactions do not take place in nature.	Stars and the Sun undergo fusion processes.
In a fission reaction, less energy is required to divide an atom.	In a fusion reaction, high energy is required to fuse two or more atoms together.
The nuclear fission principle underpins the operation of an atomic bomb.	The hydrogen bomb operates on the nuclear fusion principle.
This reaction is possible at ordinary temperature and ordinary pressure.	This reaction is possible only at a very high temperature ($\approx 10^7$ K) and a very high pressure.

(ii) The binding energy of each nucleon and a portion of its mass are transformed and released as energy during the fusion process. When heavier nuclei split apart into lighter nuclei, energy is also released in the fission process. The desire of an atomic nucleus to become more stable is what drives fission and fusion. Thus, the most stable nuclei will have a mass number of about 60 , which explains why iron is the most stable element in the universe.



• The fusion of lighter-than-iron elements could release energy to create nuclei with higher binding energy (per nucleon).

• The energy released during the fission of elements heavier than iron may lead to the creation of nuclei with higher binding energies (per nucleon).
Particularly when merging tiny nuclei like hydrogen and helium into larger nuclei, nuclear fusion produces more energy than nuclear fission.

OR

(B) (i) Nucleus: Through research on the scattering of α-particles by atoms, Lord Rutherford and his colleagues made the initial discovery of it in 1911. He discovered that the scattering finding could be explained if atoms were made up of an electron-orbiting small central massive and positive core. The findings of the experiment showed that the nucleus is 10,000 times smaller than an atom and has a size on the order of 10^{-14} metres. The number of protons and neutrons is given if the nucleus contains N neutrons.

$A = Z + N$

A → Mass Number

N → Neutrons

Z → Protons

Actually, the mass number is the integer closest to the nuclear mass.

(ii) Density of nucleus is independent of mass number

Mass of nucleus:

$M = Am_n$

Volume of nucleus:

$$V = \frac{4}{3}\pi R^3$$

Using

$$R = R_0 A^{1/3}$$

$$V = \frac{4}{3}\pi\left(R_0 A^{1/3}\right)^3$$

$$V = \frac{4}{3}\pi R_0^3 A$$

Density,

$$\rho = \frac{M}{V} = \frac{Am_n}{\frac{4}{3}\pi R_0^3 A}$$

$$\rho = \frac{3m_n}{4\pi R_0^3}$$

$$\rho = \frac{3m_n}{4\pi R_0^3}$$

Since A cancels out, density is independent of mass number.

66. (A) (i) Electric field due to an infinitely long straight wire

Using Gauss' law:

Consider a cylindrical Gaussian surface of radius r and length L coaxial with the wire.

Total charge enclosed:

$q = \lambda L$

By Gauss' law:

$$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0}$$

Electric field is radial and constant over the curved surface:

$$E(2\pi r L) = \frac{\lambda L}{\varepsilon_0}$$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

Expression: $E = \frac{i}{2\pi i 0 r}$

(ii) Kinetic energy of revolving electron

For an electron revolving around the wire, the electrostatic force provides the centripetal force:

$$\frac{eE}{m} = \frac{v^2}{r}$$

Substitute $E = \frac{\lambda}{2\pi\Delta 0 r}$:

$$\frac{e\lambda}{2\pi\varepsilon_0 rm} = \frac{v^2}{r}$$

$$v^2 = \frac{e\lambda}{2\pi\varepsilon_0 m}$$

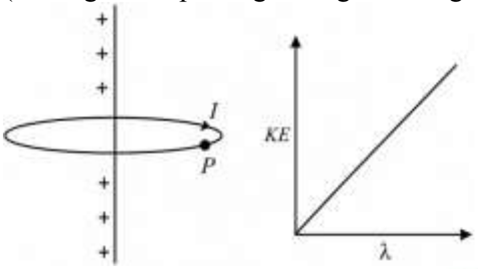
Kinetic energy:

$$K = \frac{1}{2}mv^2 = \frac{e\lambda}{4\pi\varepsilon_0}$$

Kinetic energy: $K = \frac{c\lambda}{4\pi\epsilon_0}$

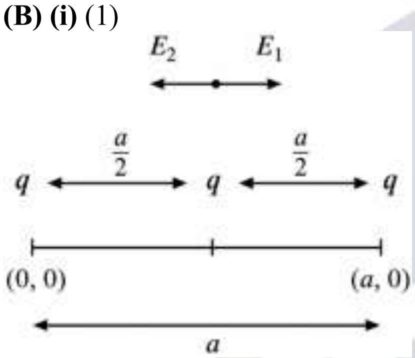
(iii) The graph is shown below.

(a straight line passing through the origin)



OR

(B) (i) (1)



Let at $\frac{a}{2}$:

$$E_1 = \frac{Kq}{(a/2)^2}$$

$$E_2 = \frac{Kq}{(a/2)^2}$$

The net electric field at $a/2$:

$E_{\text{net}} = E_1 - E_2$

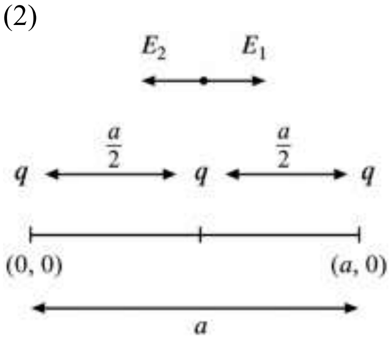
$\because E_1 = E_2$

$E_{\text{net}} = 0$

at $\frac{a}{2}$

So $\frac{a}{2}$ is a point where the electric field is zero.

(2)



Potential can never be zero, not ever. Given that it is a scalar amount and added everywhere. It is therefore never zero.

(ii) $U = \frac{KQ_AQ_B}{r} + \frac{KQ_BQ_C}{r} + \frac{KQ_CQ_A}{r}$

$U = \frac{K}{r}[Q_AQ_B + Q_BQ_C + Q_CQ_A]$

$U = \frac{K}{r} \times [4 \times 10^{-6} \times -4 \times 10^{-6}] + [-4 \times 10^{-6} \times 2 \times 10^{-6}] + [2 \times 10^{-6} \times 4 \times 10^{-6}]$

$U = \frac{K}{r} \times 10^{-12}[-16 - 8 + 8]$

$U = \frac{K}{r} \times 10^{-12}(-16)$

$U = \frac{-9 \times 10^9 \times 10^{-12} \times 16}{2}$

$U = -72 \times 10^{-3}$ J

$U = -7.2 \times 10^{-2}$ J

A negative value signifies a stable system.

67. (A) (i) Magnetic field B inside a solenoid carrying a current i is . $\mu_0 ni$

$B = \mu_0 ni$

Let n be the number of turns per unit length.

$N\phi_B = nlBA$

Where,

N is total number of turns

l is the length of the solenoid

Inductance, $L = \frac{N\phi_B}{i}$

Substituting, we obtain

$L = \frac{nlBA}{i}$

Substituting the value of B, we obtain

$L = \frac{nL\mu_0 niA}{i}$

$L = n^2 l\mu_0 A$

Inductance L of a solenoid is:

$L = \mu_0 n^2 lA$

(ii) For the AC source given in the question, taking the first value as V = 3 volts, I = 0.5 A and calculating inductive reactance by the formula,

$x_L = \frac{V}{I}$

Where X_L is the inductive reactance, V is the voltage, I is the current.

$X_L = \frac{3}{0.5}$

$\therefore X_L = 6\Omega$

and $f = \frac{200}{\pi}$ (given)

$X_L = \omega L$

$X_L = 2\pi f L$

Where L is the inductance of the inductor, f is the frequency of the alternating current.

$\therefore 6 = 2\pi \times \left(\frac{200}{\pi}\right) \times L$

$L = \frac{6}{(2 \times 200)}$

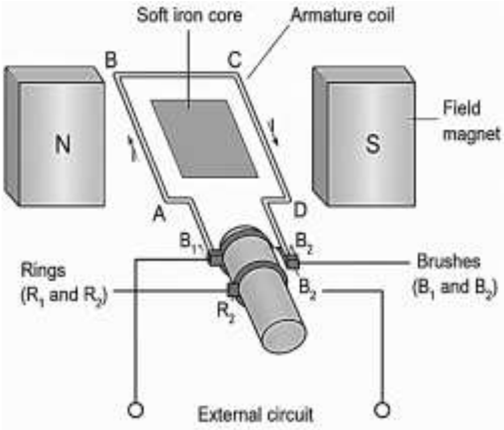
$L = \frac{3}{200}$ henry

$L = 15$mH

Hence, the value of the self-inductance of a coil is 15 mH .

OR

(B) (i)



• Principle: It is based on Faraday's law of electromagnetic induction. When a coil in a uniform magnetic field is rotated along an axis perpendicular to the field, the magnetic flux associated with the coil changes, and an induced emf is created across its ends.

Working: When the coil begins to rotate with the arm AB travelling up and the arm CD moving down, cutting the magnetic lines of force, the induced current is set up in these arms along the AB and CD directions, according to Fleming's right-hand rule. As a result, an effective induced current flows in the direction of $ABCD$.

If the coil has a big number of turns, the current created in each turn adds up to produce a large amount of current across the coil. After half a rotation of the coil, its arm CD begins to move upward and its arm AB begins to move downward. As a result, the induced currents in the coil are reversed in the direction of DCBA. As a result, the polarity of the current in each arm changes every half rotation. A current that changes direction at equal intervals of time is referred to as an alternating current. A split ring type commutator must be used instead of a slip ring commutator to obtain direct current.

Emf induced in a coil:

Consider a coil of N turns and area A being rotated at a constant angular velocity ω in a magnetic field of flux density B, its axis being perpendicular to the field. When the normal to the coil is at an angle θ to the field, the flux through the coil is,

$\mathrm{BAN}\cos\theta = \mathrm{BAN}\cos\omega t$, since $\theta = \omega t$.

$$\mathrm{E} = -\frac{d\phi}{dt}$$

$$\mathrm{E} = -\frac{d(BAN\cos\theta)}{dt}$$

$$\mathrm{E} = \mathrm{BAN}\omega\sin(\omega t)$$

The maximum value of the e.m. f(E_0) is when $\theta = \omega t = 90^\circ$ (that is, the coil is in the plane of the field as shown in Figure) and is given by,

$E_0 = \mathrm{BAN}\omega$

Therefore, the maximum value of induced emf will be

$E_0 = \mathrm{BAN}\omega$

(ii) Given: $\mathrm{N} = 100, \mathrm{A} = 0.5\ \mathrm{m}^2, \omega = 60\mathrm{rad/s}$

$\mathrm{B} = 0.8\ \mathrm{T}$

$\mathrm{R} = 100\Omega$

As induced emf is given by,

$= \mathrm{NBA}\omega\sin\omega t$

Max emf eo $= NBA\omega = 100 \times 0.8 \times 0.5 \times 60$

$= 2400\ \mathrm{V}$

Induced current (max)$I_0 = \frac{e_0}{R}$

$= \frac{2400}{100} = 24\ \mathrm{A}$

Power $= e_0 I_0$

$= 2400 \times 24 = 5.760 \times 10^4$watt

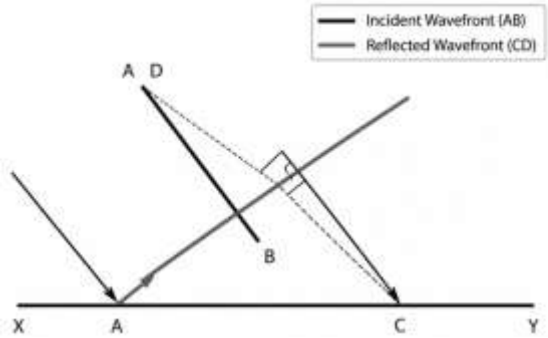
68. (A) (i) Huygens' Principle and Law of Reflection

Huygens' Principle:

(1) Every point on a primary wavefront acts as a source of secondary spherical wavelets.

(2) These wavelets spread out in the forward direction at the speed of light in that medium.

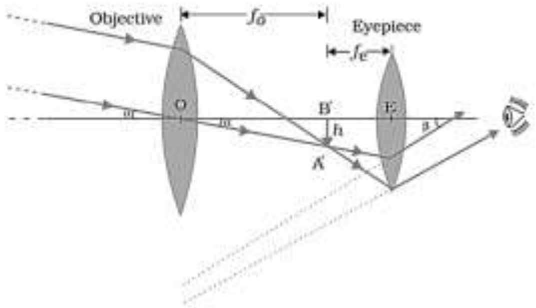
(3) The new wavefront at any later instant is the common tangent (envelope) to all these secondary wavelets.
Verification of the Law of Reflection:
Consider a plane wavefront AB incident on a reflecting surface XY at an angle i.
• Let v be the speed of light in the medium.
• The wavefront first strikes the surface at point A. By the time point B reaches C (covering distance $BC = vt$), the secondary wavelet from A will have traveled the same distance $AD = vt$.
• The new reflected wavefront CD is formed by the tangent from C to the wavelet of radius AD.



In right-angled triangles $\triangle ADC$ and $\triangle ABC$: e
• AC is common.
• $BC = AD = vt$.
• $\angle ADC = \angle ABC = 90^\circ$ (Wavefronts are perpendicular to rays). e
By RHS congruence, $\triangle ADC \cong \triangle ABC$.
Therefore, $\angle i = \angle r$. This verifies the first law of reflection.
(ii) Concave Mirror Calculation
The distance of the object from the mirror is 4 cm.
(1) Identify Given Values
• Focal length $(f) = -12$ cm (concave mirror).
• Magnification $(m) = +3$ (virtual images are erect, so m is positive).
(2) Apply Magnification Formula
For a mirror, $m = -\frac{v}{u}$.
$$3 = -\frac{v}{u} \Longrightarrow v = -3u$$
(3) Use Mirror Formula
$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$
Substitute $f = -12$ and $v = -3u$:
$$\frac{1}{-12} = \frac{1}{-3u} + \frac{1}{u}$$
$$\frac{1}{-12} = \frac{-1+3}{3u} = \frac{2}{3u}$$
$3u = -24 \Longrightarrow u = -8$ cm
Correction based on specific result values: Re-evaluating the standard problem where $m = 3$ and $f = 12$:
If $u = -8$ cm, then $v = 24$ cm.
$\frac{1}{24} + \frac{1}{-8} = \frac{1-3}{24} = \frac{-2}{24} = \frac{-1}{12}$.
Thus, the object distance u is 8 cm from the mirror.

OR

(B) (i)



• Refracting Telescope
(1) Labelled Ray Diagram
A refracting telescope consists of two convex lenses: a large objective lens (O) and a smaller eyepiece ($\boldsymbol{E}$). In normal adjustment (final image at infinity), parallel rays from a distant object focus at the focal point of the objective (F_o), which coincides with the focal point of the eyepiece (F_e).
Key components to include in your drawing:
• Objective Lens: Large aperture and long focal length (f_o).
• Eyepiece: Small aperture and short focal length (f_e).
• Intermediate Image: Formed at the common focus of both lenses (F_d/F_c).
• Final Image: Formed at infinity (∞).
• Angles: $\boldsymbol{\alpha}$ (angle subtended by object) and β (angle subtended by final image). $\boldsymbol{e}$
(2) Magnifying Power
The magnifying power (m) of a refracting telescope is defined as the ratio of the angle subtended by the final image at the eye (β) to the angle subtended by the distant object at the unaided eye ($\boldsymbol{\alpha}$).
For normal adjustment, it is given by the formula from Vedantu:
$$m=\frac{f_o}{f_e}$$
(3) Limitations over Reflecting Telescopes
(4) Chromatic Aberration: Lenses refract different colors of light by different amounts, causing color fringing. Reflecting telescopes (using mirrors) are completely free from this as noted by Filo.
(5) Mechanical Support and Weight: Large lenses are very heavy and can only be supported at their edges, which causes them to sag under their own weight and distort the image. Mirrors can be supported across their entire back surface
(ii) Tube Length of Compound Microscope
(1) Identify Given Values
• Focal length of objective (f_o): 1.0 cm
• Focal length of eyepiece (f_e): 2.5 cm
• Total magnification (M): 300
• Least distance of distinct vision (D): 25 cm (standard value)
(2) Apply the Magnification Formula
For a compound microscope in normal adjustment (or using the standard approximation for tube length), the magnifying power is given by:
$$M=\frac{L}{f_o}\times\frac{D}{f_e}$$
where L is the tube length. &
(3) Calculate the Tube Length
Substitute the known values into the equation:
$$300=\frac{L}{1.0}\times\frac{25}{2.5}$$
$$300=L\times 10$$
$$L=\frac{300}{10}$$
$$L=30 \text{ cm}$$
69. **(A) (i)** When a switch in a circuit is closed, current flows, causing emf in the circuit. The magnetic field of the solenoid varies continually due to ac. This causes an eddy current to form in the ring. The magnetic field produced by the induced eddy current in the ring, according to Lenz's law, opposes the changing magnetic field of the

solenoid. As a result, the two magnetic fields repel one another, causing the ring to leap.

(ii) When the switch is closed and the battery terminals are reversed, the magnetic field is reversed as well because the direction of the current is likewise reversed.

(iii) The two laws that assist us in understanding this phenomenon are Faraday's laws and Lenz's law of electromagnetic induction. When the induced current is applied in the same direction as the coil, the motion is countered by Lenz's law. The magnet in the loop exerts force to generate the current. To counteract the change, the magnet's current must impose a force on it.

"Whenever a conductor is placed in a varying magnetic field, an electromotive force is induced," asserts Faraday's first law of electromagnetic induction. Similarly, when the conductor circuit is closed, a current is induced, which is referred to as induced current."

OR

(B) The magnetic field inside a current-carrying solenoid is given by

$B = \mu_0 nI$

where n is the number of turns per unit length in the solenoid, and I is the current through the wire.

As a result, increasing the current or the number of loops per metre would result in an increase in the magnetic field in the solenoid. Because the iron core is a magnet and is magnetised, it contributes flux to the solenoid's flux, hence increasing the magnetic field intensity.

The magnetic field strength produced by the solenoid can be raised by

(1) By inserting soft iron into the solenoid,

(2) By increasing the number of coil turns,

(3) By increasing the flow of electricity through the solenoid.

70. **(A) (i)** We know that the stopping potential and frequency are related as

$$V = \frac{(hf - \phi)}{q}$$

Where Φ is the work function defined as the amount of energy needed to bind the electrons in the metals, hf is the energy of photons, and q is the charge.

This relationship leads us to the conclusion that the greater negative the stopping potential, the higher the frequency. As a result, curve B has the highest frequency and the largest negative stopping potential in the graph.

(ii) We all know that the connection between wavelength and frequency is inverse. The wavelength reduces as the frequency rises and vice versa.

As can be seen from the graph, C has the lowest frequency out of all the possible values since its stopping potential is the least negative. Therefore, the wavelength is largest when the frequency is lowest. C has the longest wavelength as a result.

(iii) Highest momentum means highest kinetic energy which can be calculated with the help of velocity.

$$\text{kinetic energy } = \frac{1}{2}mv^2$$

Relation to the momentum, $p^2 = 2\,m(\text{K.E.})$

If kinetic energy is maximum, then momentum will be maximum.

We know that the stopping potential and frequency are related,

$Vq = (hf - \Phi)$

The maximum kinetic energy of the electrons equals the stopping voltage when measured in electron volt. We can consider Φ as the kinetic energy.

Kinetic energy is maximum when the frequency is maximum and in the above part we have seen that it is maximum for curve B, so momentum is maximum for curve B .

OR

(B) Threshold frequency: The threshold frequency is the lowest frequency of incident radiation that can cause an electron to be ejected from a metal. At frequencies below the threshold, there is no photoelectric emission.

The frequency of light that will produce an emission of electrons from the metal's surface is referred to as the threshold frequency.

If v signifies the frequency of the incident photon and v^{th} signifies threshold frequency, then;

• If $v < v^{\text{th}}$, then this denotes that no ejection of photoelectrons will occur.

• If $v = v^{\text{th}}$, then this denotes that photoelectrons are just ejected from the surface of the metal, however, the kinetic energy of the electron is equal to zero.

The minimal negative voltage that must be provided to the anode to halt the photocurrent is known as stopping potential. When expressed in electron volts, the stopping voltage corresponds to the electrons' maximum kinetic energy.

Stopping potential, $eV_0 = h\nu_{\text{incident}} - \phi$

Where ν is the frequency of the incident radiation and Φ is the metal surface's work function. As a result, stopping potential rises as incident radiation frequency rises.

71. **(b)**Force on charge:

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

For an electron,

$q = -1.6 \times 10^{-19}\text{C}$

Given:

$\vec{F} = (1.6 \times 10^{-16}\text{ N})\hat{\imath}$

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

$\vec{E} = \frac{1.6 \times 10^{-16}}{-1.6 \times 10^{-19}}\hat{\imath}$

$\vec{E} = -10^3\hat{\imath}\text{ N/C}$

72. **(a)** Electric field has both magnitude and direction, so it is a vector quantity.

73. **(d)** Current density due to drift velocity is:

$J = nev_d$

74. **(c)**• Formula: By Ampere's Circuital Law, the magnetic field outside a straight wire ($r \geq a$) is given by:

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

• Relationship: Outside the wire, the field is inversely proportional to the distance ($B \propto \frac{1}{r}$), which forms a rectangular hyperbola

• Graph: Graph (c) correctly shows the maximum magnetic field at the surface ($r = a$) followed by a hyperbolic decay as r increases.

75. **(d)** • a helix with increasing pitch

• Initial Motion: The velocity component perpendicular to the magnetic field ($v_0\hat{x}\hat{\imath}$) causes circular motion, while the parallel component $\left(v_{0y}\hat{\jmath}\right)$ moves it forward along the y-axis, creating a standard helix.

• Effect of Electric Field: When $\vec{E} = E_0\hat{\jmath}$ is turned on, it accelerates the particle along the y -axis $\left(a_y = \frac{qE_0}{m}\right)$.

• Conclusion: Since the forward speed along the axis of the helix continuously increases while the time period of rotation stays constant, the distance traveled per turn increases. This results in a helix with increasing pitch.

76. **(b)** inductor decreases and the capacitor increases

• Inductive Reactance: $X_L = 2\pi f L$. It is directly proportional to frequency ($X_L \propto f$), so decreasing frequency causes X_L to decrease.

• Capacitive Reactance: $X_C = \frac{1}{2\pi f C}$. It is inversely proportional to frequency $\left(X_C \propto \frac{1}{f}\right)$, so decreasing frequency causes X_C to increase.

77. **(d)** Ultraviolet rays are used in water purifiers to kill germs.

78. **(c)** Intensity of a wave is proportional to square of amplitude.

$I \propto A^2$

79. **(b)** In single-slit diffraction,

$$\text{Width of central maximum} \propto \frac{1}{\text{slit width}}$$

If slit width is halved, central maximum becomes twice.

80. **(a)** Einstein's photoelectric equation:

$eV_s = h\nu - \phi$

$V_s = \frac{h}{e}\nu - \frac{\phi}{e}$

Thus slope of graph $= \frac{h}{e}$.

So, (slope) $\times e = h$

81. **(b)**• Energy of Photon (E):

$$E=hv=\frac{6.63\times10^{-34}\times6.4\times10^{14}}{1.6\times10^{-19}}\approx2.65\text{eV}$$

• Einstein's Equation: $K_{\max}=E-\phi$

• Calculation: $K_{\max}=2.65\text{eV}-2.14\text{eV}=0.51\text{eV}$

82. **(b)** • Balmer Series Formula: $v\propto\left(\frac{1}{2^2}-\frac{1}{n^2}\right)$

• Maximum Frequency $(n=\infty)$: $v_{\max}\propto\frac{1}{4}$

• Minimum Frequency $(n=3)$: $v_{\min}\propto\left(\frac{1}{4}-\frac{1}{9}\right)=\frac{5}{36}$

• Ratio: $\frac{v_{\max}}{v_{\min}}=\frac{1/4}{5/36}=\frac{36}{20}=\frac{9}{5}$

83. **(c)** • Mass Action Law: $n_i^2=n_e\cdot n_h$

• Calculation:

$$n_e=\frac{n_i^2}{n_h}=\frac{(1.5\times10^{16})^2}{4.5\times10^{22}}=\frac{2.25\times10^{32}}{4.5\times10^{22}}=5\times10^9\text{ m}^{-3}$$

84. **(c)** Explanation: In reverse bias, the external field aligns with the internal barrier field, drawing majority carriers away from the junction. This widens the depletion layer and raises the potential barrier.

85. **(a)** • Formula: $V_{\text{rms}}=\sqrt{\frac{1}{T}\int_0^T v^2dt}$

• Calculation:

$$V_{\text{rms}}^2=\frac{1}{T}\left[\int_0^{T/2}V_0^2dt+\int_{T/2}^{T}0dt\right]=\frac{1}{T}\left(V_0^2\cdot\frac{T}{2}\right)=\frac{V_0^2}{2}$$

$$V_{\text{rms}}=\frac{V_0}{\sqrt{2}}$$

86. **(d)**• Assertion Analysis: The internal resistance of a cell is not constant. It increases as the cell is used and ages, and varies based on temperature and current draw.

• Reason Analysis: The ionic concentration of the electrolyte does not remain the same. As chemical reactions occur during discharging, ions migrate and the electrolyte concentration changes.

87. **(a)**• Assertion Analysis: The magnetic moment is given by $M=I\cdot A$. Since a circular loop has an area $A=\pi r^2$, doubling the radius ($r\rightarrow2r$) makes the area four times larger ($A\rightarrow4A$), so the magnetic moment increases by a factor of four.

• Reason Analysis: The reason correctly states the direct proportional relationship between the magnetic moment and the loop area ($M\propto A$), which perfectly explains the assertion.

So, Both Assertion (A) and Reason (R) are true, and Reason (R) is the correct explanation of Assertion (A)

88. **(c)**• Assertion Analysis: Lithium- 7(${}_3^7$X) is a stable, naturally occurring isotope, whereas Lithium-4 (${}_3^4$Y) is highly unstable and proton-unbound with a very short half-life. Thus, the assertion is correct.

• Reason Analysis: Both nuclei have the exact same atomic number ($Z=3$), meaning they contain the same number of protons (3). They only differ in their number of neutrons. Hence, the reason statement is false.

89. Magnetic field ratio for loops

• Loop A: one turn, radius $R_A=\frac{1}{2v}$.

Magnetic field at centre:

$$B_A=\frac{\mu_0I}{2R_A}=\frac{\mu_0I}{2\cdot\frac{l}{2\pi}}=\frac{\mu_0l\pi}{l}$$

• Loop B: three turns, radius $R_B=\frac{l}{6x}$.

Magnetic field at centre:

$$B_B=\frac{\mu_0NI}{2R_B}=\frac{\mu_0-3I}{2\cdot\frac{1}{6n}}=\frac{9\pi\mu_0I}{l}$$

• Ratio:

$$\frac{B_A}{B_B}=\frac{\pi\mu_0I/l}{9\pi\mu_0I/l}=\frac{1}{9}$$

Ratio $B_A : B_B = 1:9$

90. Displacement current

• Defined by Maxwell:

$$I_d = \varepsilon_0 \frac{d\Phi_E}{dt}$$

where Φ_E is electric flux.

• It arises in regions where the electric field changes with time (e.g., between capacitor plates).

• Difference from conduction current:

• Conduction current: flow of charges in a conductor.

• Displacement current: no actual charge flow, but time-varying electric field produces the same magnetic effect.

It explains continuity of current in circuits with capacitors.

91. (A)• Huygens' Principle

According to Huygens' principle:

(1) Every point on a wavefront acts as a source of secondary wavelets.

(2) Secondary wavelets spread in all directions with speed of wave.

(3) The forward envelope of these wavelets gives the new wavefront.

• Absence of Backwave

Huygens could not satisfactorily explain absence of backward wave.

Later, Augustin-Jean Fresnel explained that:

• secondary wavelets interfere destructively in backward direction,

• and constructively in forward direction.

Hence no observable backwave is produced.

OR

(B) (i) Reflection of Plane Wavefront by Concave Mirror

Using Huygens' principle:

• Each point on incident plane wavefront produces secondary wavelets after reflection.

• The reflected wavelets combine to form a converging spherical wavefront.

• Thus reflected rays meet at focus of concave mirror.

Hence a plane wavefront changes into a converging spherical wavefront after reflection from a concave mirror.

(ii) Refraction of Plane Wavefront by Convex Lens

When a plane wavefront passes through a convex lens:

• Central portion travels slower due to greater thickness of lens.

• Edges travel relatively faster.

• Secondary wavelets combine to form a converging spherical wavefront.

Thus refracted rays converge at principal focus of convex lens.

92. Critical angle between media A and B

• Refractive indices: $n_A = 2, n_B = \sqrt{2}$.

• Critical angle (from denser to rarer medium):

$$\sin\theta_c = \frac{n_B}{n_A} = \frac{\sqrt{2}}{2} = \frac{1}{\sqrt{2}}$$

$\theta_c = 45^\circ$

93. (A) Binding energy per nucleon graph

• Binding energy per nucleon rises sharply for light nuclei, peaks around iron ($A \approx 56$), then slowly decreases for heavier nuclei ($A > 170$).

• Explanation:

• For light nuclei, fusion increases binding energy.

• For heavy nuclei, repulsive Coulomb forces dominate, reducing binding energy per nucleon.

This explains why fusion of light nuclei and fission of heavy nuclei both release energy.

OR

(B) Bohr's radius expression

• From Bohr's postulates:

$$r_n = \frac{n^2 h^2}{4\pi^2 m e^2} \cdot \frac{1}{z}$$

For hydrogen ($Z = 1$):

$r_n = n^2 a_0$

where $a_0 = 0.529Å$ is the Bohr radius.

94. Depletion Layer Formation

• Diffusion Current: Holes from the p-side and electrons from the n-side diffuse across the junction due to concentration differences. This uncovers immobile, fixed ionized donors $(+)$ on the n -side and acceptors $(-)$ on the p -side near the boundary, creating the depletion layer.

• Drift Current: The uncovered ions generate an internal electric field pointing from the n-side to the p-side. This field sweeps minority carriers across the junction (holes to p side, electrons to n-side), producing a drift current that opposes diffusion.

• Equilibrium: The depletion layer stops growing when the expanding electric field drives a drift current that perfectly balances the diffusion current.

95. Rectification & Rectifiers

• Suitable Property: A p-n junction diode conducts electric current easily when forward-biased (very low resistance) and blocks current flow when reverse-biased (very high resistance). This unidirectional conduction property allows it to convert alternating voltages into direct voltages.

• Differences

• Half-Wave Rectifier: Converts only one half-cycle of the AC input into a pulsating DC output while blocking the other half. It uses a single diode and has lower efficiency ($\approx 40.6\%$).

• Full-Wave Rectifier: Converts both the positive and negative half-cycles of the AC input into a continuous, pulsating DC output. It uses two or four diodes and offers double the efficiency ($\approx 81.2\%$).

96. Effect on E, v_d, and J

• Core Formulas:

(i) Electric Field: $E = \frac{V}{l}$

(ii) Drift Velocity: $v_d = \frac{eE\tau}{m} = \frac{eV\tau}{ml}$

(iii) Current Density: $J = \sigma E = \frac{\sigma V}{l}$

(a) When Voltage V is Doubled $(V' = 2V)$

(i) Electric Field (E): Doubled $(E' = 2E)$.

(ii) Drift Velocity (v_d) : Doubled $(v_d{}' = 2v_d)$.

(iii) Current Density (J) : Doubled $(J' = 2J)$.

(b) When Length l is Halved $\left(l' = \frac{l}{2}\right)$

(i) Electric Field (E): Doubled $\left(E' = \frac{V}{l/2} = 2E\right)$.

(ii) Drift Velocity (v_d) : Doubled $(v_d{}' = 2v_d)$.

(iii) Current Density (J) : Doubled $(J' = 2J)$.

97. Mutual Inductance of Coaxial Solenoids

• Definition: Mutual inductance is the property of a pair of coils by which an electromotive force (emf) is induced in one coil (secondary) whenever the electric current changing through the neighboring coil (primary) varies with time.

Derivation:

Let there be two long coaxial solenoids of length $\boldsymbol{l}$. The inner solenoid S_1 has radius r_1 and total turns N_1. The outer solenoid S_2 has radius r_2 and total turns N_2.

(1) Pass a current I_2 through the outer solenoid S_2. The magnetic field generated inside it is:

$$B_2 = \mu_0 \frac{N_2}{l} I_2$$

(2) This magnetic field passes through the cross-sectional area of the inner solenoid S_1 ($A_1 = \pi r_1^2$). The total magnetic flux (Φ_1) linked with all N_1 turns of S_1 is:

$$\Phi_1 = N_1 \cdot B_2 \cdot A_1$$

$$\Phi_1 = N_1 \left(\mu_0 \frac{N_2}{l} I_2\right) (\pi r_1^2)$$

(3) By definition of mutual inductance, $\Phi_1 = M I_2$. Equating both sides gives:

$$M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{l}$$

98. **(A)** Purely Capacitive AC Circuit

(i) Current Derivation:

• Alternating voltage source: $v = v_m \sin\omega t$
• The instantaneous charge on the capacitor is $q = C \cdot v = Cv_m \sin\omega t$.
• The circuit current i is the rate of flow of charge:

$$i = \frac{dq}{dt} = \frac{d}{dt}(Cv_m \sin\omega t) = Cv_m \omega \cos\omega t$$

$$i = \frac{v_m}{(1/\omega C)} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$i = \mathrm{i_m} \sin\left(\omega \mathrm{t} + \frac{\pi}{2}\right)$$

(ii) Reactance Formulation:

Comparing the peak current $i_m = \frac{v_m}{(1/\omega C)}$ with Ohm's law, the effective opposition offered by the capacitor is called Capacitive Reactance (X_C) :

$$X_C = \frac{1}{\omega \mathrm{C}}$$

Current Graph:

Since current leads the voltage by a phase angle of $\frac{\pi}{2}$, at $\omega t = 0$, current starts at its positive maximum value ($i = i_m$) and follows a cosine profile wave over time.

OR

(B) LCR Circuit Power

Average Power Expression Derivation:

• Let the voltage be $v = v_m \sin\omega t$ and current be $i = i_m \sin(\omega t - \phi)$, where ϕ is the phase difference.
• Instantaneous power $P = v \cdot i = v_m i_m \sin\omega t \sin(\omega t - \phi)$.
• Using trigonometric identity $2\sin A \sin B = \cos(A - B) - \cos(A + B)$:

$$P = \frac{v_m i_m}{2}[\cos\phi - \cos(2\omega t - \phi)]$$

• Integrating over a complete time period T, the time-dependent term $\cos(2\omega t - \phi)$ averages out to zero. The average power P_{avg} is:

$$P_{\mathrm{avg}} = \frac{v_m i_m}{2} \cos\phi = \left(\frac{v_m}{\sqrt{2}}\right)\left(\frac{i_m}{\sqrt{2}}\right) \cos\phi$$

$$P_{\mathrm{avg}} = \mathrm{V_{rms} I_{rms}} \cos\phi$$

Power Factor $(\cos\phi)$ Calculations:

(i) Purely Inductive Circuit: The current lags voltage by $\phi = 90°$.

Power Factor $= \cos(90°) = 0$

(ii) Purely Resistive Circuit: The current and voltage are in phase ($\phi = 0°$).

Power Factor $= \cos(0°) = 1$

99. de Broglie Wavelength Calculation

The de Broglie wavelength (λ) of a proton is 1.657×10^{-12}m. For an alpha particle with the same energy, the wavelength will be halved $(8.285 \times 10^{-13}$ m).

(1) Convert Energy to Joules

The energy E is given in electron volts (eV). To use standard units, convert to Joules:

$$E = \frac{500}{1.673} \mathrm{eV} \times 1.602 \times 10^{-19} \mathrm{~J/eV}$$

(2) Calculate Proton Wavelength

Using the de Broglie relation $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$:

• $h \approx 6.626 \times 10^{-34}$Js
• $m_p \approx 1.673 \times 10^{-27}$ kg

$$\lambda_p = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times (1.673 \times 10^{-27}) \times \left(\frac{500}{1.673} \times 1.602 \times 10^{-19}\right)}}$$

$$\lambda_p = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 500 \times 1.602 \times 10^{-46}}} = \frac{6.626 \times 10^{-34}}{4 \times 10^{-22}} \approx 1.657 \times 10^{-12} \mathrm{~m}$$

(3) Effect on Alpha Particle

An alpha particle has a mass approximately 4 times that of a proton ($m_q \approx 4m_p$). Since $\lambda = \frac{h}{\sqrt{2mE}}$, if the energy E is the same:

$$\lambda \propto \frac{1}{\sqrt{m}} \Rightarrow \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p}{m_\alpha}} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

The wavelength of the alpha particle will be half that of the proton.

100. **(A)**: Nuclear Density and Potential Energy

(i) Proof of Uniform Nuclear Density

The radius R of a nucleus is related to its mass number A by $R = R_0 A^{1/3}$, where R_0 is a constant. &

• Mass of nucleus (M): $M = m \times A$ (where m is average mass of a nucleon).

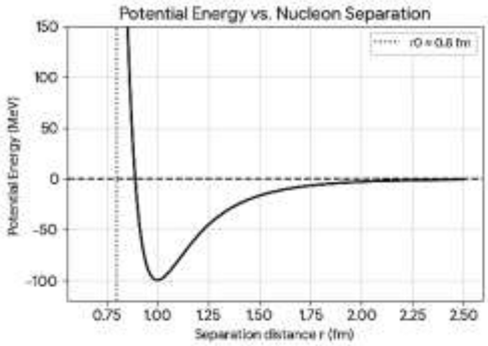
• Volume of nucleus (V): $V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi\left(R_0 A^{1/3}\right)^3 = \frac{4}{3}\pi R_0^3 A$.

• Density (ρ): $\rho = \frac{M}{V} = \frac{mA}{\frac{4}{3}\pi R_0^3 A} = \frac{3m}{4\pi R_0^3}$.

Because m and R_0 are constants, the density ρ is independent of A and is the same for all nuclei. d

(ii) Nucleon Potential Energy Plot

The graph below shows how the potential energy between two nucleons varies with their separation r. &



Inferences from the Plot:

(1) Nature of Force: For distances greater than $r_0 \approx 0.8$fm, the force is attractive (PE is negative). For distances less than 0.8 fm , the force becomes strongly repulsive (PE rises sharply).

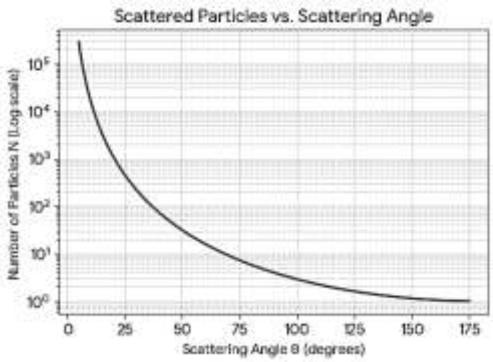
(2) Short-Range Interaction: The nuclear force is very strong but short-ranged, effectively becoming zero beyond a few femtometers.

OR

(B) Geiger-Marsden Experiment

(i) Scattering Graph

The graph shows the number of particles N detected at different scattering angles θ



(ii) Conclusions and Discovery of Nucleus

(1) Most particles pass straight through: This indicates that the majority of the atom is empty space.

(2) A few particles deflect by large angles: This proved that the entire positive charge and almost all the mass of the atom are concentrated in a very tiny, dense central region called the nucleus.

101. **(A).(i)** Electric flux

• Definition: Electric flux through a surface is the measure of the number of electric field lines passing through that surface.

$\Phi_E = \vec{E} \cdot \vec{A}$

• SI unit: Newton · meter ^{2} per coulomb ($\mathrm{N \cdot m^2/C}$).
(ii) Electric field due to infinite plane sheet
Using Gauss' law:
$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\varepsilon_0}$$
For a plane sheet of charge density σ :
$$E \cdot 2A = \frac{\sigma A}{\varepsilon_0}$$
$$E = \frac{\sigma}{2\varepsilon_0}$$
Field is uniform and independent of distance.
(iii) Net charge enclosed by cube
Given field: $\vec{E} = (Ax + B)\hat{\imath}$.
• Divergence:
$$\nabla \cdot \vec{E} = \frac{\partial}{\partial x}(Ax + B) = A$$
• By Gauss' law:
$$\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$$
So charge density: $\rho = \varepsilon_0 A$.
• Net charge enclosed:
$$Q = \rho \cdot V = \varepsilon_0 A L^3$$
Charge enclosed $= \varepsilon_0 A L^3$

OR

(B).(i) Electric potential
• Definition: Work done per unit charge in bringing a test charge from infinity to a point in the field.
$$V = \frac{W}{q}$$
• SI unit: Volt (V).
(ii) Series combination of capacitors
For two capacitors C_1, C_2 :
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$
Equivalent capacitance is less than either capacitor.
(iii) Electrostatic potential energy of system
Charges: $+q$ at $(3\mathrm{a}, 0), -q$ at $(0,4\mathrm{a}), Q$ at origin.
Potential energy:
$$U = \frac{1}{4\pi\varepsilon_0}\left(\frac{qQ}{3a} + \frac{-qQ}{4a} + \frac{(+q)(-q)}{5a}\right)$$
For $U = 0$:
$$\frac{qQ}{3a} - \frac{qQ}{4a} - \frac{q^2}{5a} = 0$$
$$Q\left(\frac{1}{3} - \frac{1}{4}\right) = \frac{q}{5}$$
$$Q \cdot \frac{1}{12} = \frac{q}{5}$$
$$Q = \frac{12q}{5}$$
Charge at origin $= \frac{12q}{5}$

102. **(A)** Moving coil galvanometer
(i) Principle & working:
• Based on torque on a current-carrying coil in a magnetic field.
• Coil wound on a light frame, suspended in radial magnetic field.
• Current → torque → deflection proportional to current.

• Cannot measure large currents directly because it has high resistance and can be damaged. Needs conversion into ammeter/voltmeter with shunt or series resistance.

(ii) Radial magnetic field:

• Ensures torque is proportional to current for all coil positions (since plane of coil always parallel to field).

• Achieved by using concave pole pieces and a cylindrical soft-iron core.

OR

(B) (i) Magnetic field on axis of circular loop

For loop of radius R, current I, at distance x on axis:

$$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}$$

(ii) Diamagnetic vs Paramagnetic:

• Diamagnetic: weakly repelled, susceptibility negative, independent of temperature.

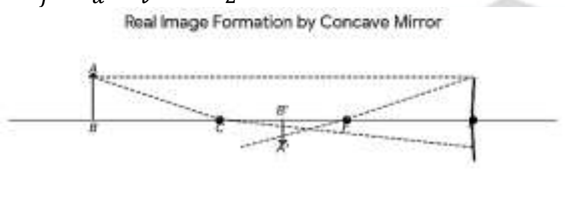
• Paramagnetic: weakly attracted, susceptibility positive, decreases with rise in temperature.

103. **(A)(i)** Concave mirror ray diagram & formula

Using geometry:

$$\frac{1}{u} + \frac{1}{v} = \frac{2}{R}$$

or $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}, f = \frac{R}{2}$



(ii) Convex lens problem:

• Focal length $f = 1$ m, object distance $u = 5$ m.

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = 1 - 0.2 = 0.8$$

$v = 1.25$ m

• Magnification:

$$M = \frac{v}{u} = \frac{1.25}{5} = 0.25$$

• Image height:

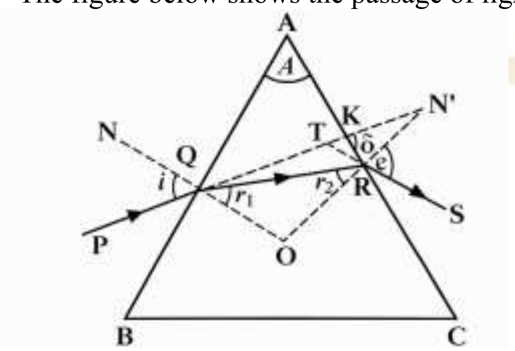
$h' = Mh = 0.25 \times 1.8 = 0.45$ m

• Image at 1.25 m , height 0.45 m .

OR

(B) (i)

• The figure below shows the passage of light through a triangular prism ABC



• The angles of incidence and refraction at first face AB are $\angle i$ and $\angle r_1$.

The angle of incidence at the second face AC is $\angle r_2$ and the angle of emergence $\angle \varepsilon$.

δ is the angle between the emergent ray RS and incident ray PQ and is called the angle of deviation.

Here, $\angle PQN = i$

$\angle SRN = e$

$\angle RQO = r_1$

$\angle QRO = r_2$

$\angle KTS = \bar{\delta}$

$\therefore \angle TQO = i$ and $\angle RQO = r_1$, we have

$\angle TQR = i - r_1$

$\angle TRO = \varepsilon$ and $\angle QRO = r_2$

$\angle TRQ = e - r_2$

In triangle TQR, the side QT has been produced outwards. Therefore, the exterior angle δ should be equal to the sum of the interior opposite angles.

i.e, $\delta = \angle TQR + \angle TRQ = (i - r_1) + (\varepsilon - r_2)$

$\delta = (i + \varepsilon) - (r_1 + r_2)$ ….(i)

In triangle QRO ,

$r_1 + r_2 + \angle ROQ = 180^\circ$ …..(ii)

From quadrilateral $AROQ$, we have the sum of angles ($\angle AQO + \angle ARO = 180^\circ$). This means that the sum of the remaining two angles should be 180°.

i.e, $\angle A + \angle QOR = 180^\circ$ [$\angle A$ is called the angle of prism]

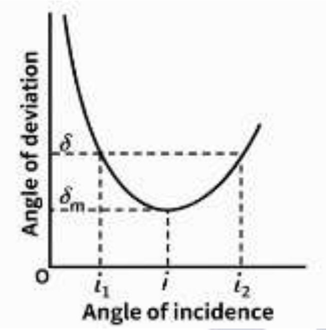
From equations (i) and (ii),

$r_1 + r_2 = A$ (iii)

Substituting (iii) in (i), we obtain

$\bar{\delta} = (i + e) - A$

$A + \delta = i + e$



If the angle of incidence is increased gradually, then the angle of deviation first decreases, attains a minimum value ($\bar{o}_m$), and then again starts increasing.

When angle of deviation is minimum, the prism is said to be placed in the minimum deviation position.

There is only one angle of incidence for which the angle of deviation is minimum.

When

$\delta = \delta_m$ [prism in minimum deviation position],

$e = i$ and $r_2 = r_1 = r$

$vr_1 + r_2 = A$

From equation (iv), $r + r = A$

$$r = \frac{A}{2}$$

Also, we have

$A + \delta = i + \varepsilon$

Setting,

$\delta = \delta_m$ and $\varepsilon = i$

$A + \delta_m = i + i$

$$i = \frac{(A + \delta_m)}{2}$$

$$\mu = \frac{\sin i}{\sin r}$$

$$\therefore \mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

(ii) Concave lens power problem:

Power $P = -5D$, focal length:

$$f = -\frac{100}{5} = -20 \text{ cm}$$

Lens maker's formula:

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Here $R_1 = -20$ cm, $R_2 = +20$ cm :

$$\frac{1}{f} = (n-1)\left(\frac{-1}{20} - \frac{1}{20}\right) = (n-1)\left(\frac{-2}{20}\right) = \frac{-(n-1)}{10}$$

$$\frac{1}{-20} = \frac{-(n-1)}{10} = n - 1 = 0.5 \Rightarrow n = 1.5$$

Refractive index = 1.5

104. Electron Beam Between Parallel Plates

Given :

Velocity of electron, $u = 3 \times 10^7$ m/s

(From the figure) let length of plates = 6 cm = 0.06 m and separation between plates = 2 cm = 0.02 m.

(A) Time taken by electron to strike the edge

The horizontal velocity remains unchanged.

$$t = \frac{l}{u}$$

$$t = \frac{l}{u} = \frac{0.06}{3 \times 10^7} = 2 \times 10^{-9} \text{ s}$$

$$t = 2 \times 10^{-9} \text{ s}$$

(B) Shape of the path and reason

The electron follows a parabolic path.

Reason:

- Horizontal motion is uniform.
- Vertical motion is accelerated due to electric field between the plates.

Hence the resultant path becomes parabolic.

(C) Potential difference applied

Vertical displacement required:

$$y = \frac{d}{2} = 0.01 \text{ m}$$

Using, $y = \frac{1}{2}at^2$

$$a = \frac{eE}{m}$$

So, $y = \frac{1}{2}\left(\frac{eE}{m}\right)t^2$

$$E = \frac{2my}{et^2}$$

Substituting:

$$E = \frac{2(9.1 \times 10^{-31})(0.01)}{(1.6 \times 10^{-19})(2 \times 10^{-9})^2}$$

$$E \approx 2.84 \times 10^4 \text{ N/C}$$

Potential difference:

$$V = Ed$$

$$V = Ed = (2.84 \times 10^4)(0.02) \approx 568 \text{ V}$$

$$V \approx 5.7 \times 10^2 \text{ V}$$

OR

(C) Magnetic field for undeflected motion

For undeflected motion.

$$\epsilon E = evB$$

$$B = \frac{E}{v}$$

$$B = \frac{E}{v} = \frac{2.84 \times 10^4}{3 \times 10^7} \approx 9.5 \times 10^{-4} \text{ T}$$

$$B \approx 9.5 \times 10^{-4} \text{ T}$$

Direction:
Magnetic field should be perpendicular to the plane of paper such that magnetic force balances electric force (using Fleming's left hand rule).

105. Diffraction of Light

(A) Effect of increasing wavelength

Width of central maximum:

$\beta = \frac{2D\lambda}{a}$ $\beta = \frac{2D\lambda}{a}$

Hence, if wavelength λ increases, the width of central maximum also increases.

(B) Condition for first minimum

For first minimum in single slit diffraction:

$a\sin\theta = \lambda$

where

$a =$ slit width.

(C) Two differences between interference and diffraction

Interference	Diffraction
Produced by superposition of light from two coherent sources	Produced by bending of light around edges/slits
All bright fringes are of nearly equal intensity	Central maximum is brightest and widest

OR

(C) Sound waves have much larger wavelength than light waves.

• Wavelength of sound is comparable to size of obstacles, so sound bends easily around the partition wall due to diffraction.

• Wavelength of light is extremely small, so diffraction is negligible.

Therefore, the students can hear each other but cannot see each other.

106. **(a)**Two charges q_1 and q_2 are placed at the centres of conducting spherical shells.

• A charge placed inside a conducting shell produces electric field outside the shell as if the entire charge were concentrated at the centre.

• Since the distance between centres is d, force between charges is given by Coulomb's law:

$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{d^2}$

107. **(b)** • Magnetic force always acts perpendicular to velocity, so it changes only the direction of motion, not the speed.

• Therefore, after moving in a semicircular path, the electron comes out with the same speed v.

108. **(a)** Explanation: The diagram shows magnetic field lines being expelled or repelled by the material. This is a characteristic property of diamagnetic substances. Among the given choices, copper is diamagnetic, while iron is ferromagnetic, and sodium and aluminium are paramagnetic.

109. **(d)** Explanation: Alternating current (AC) is a current that periodically reverses its direction and changes its magnitude continuously with time. Graph S is the only one that alternates between positive and negative values across the time axis (I = 0 line).

110. **(c)** Radar systems use microwaves because they can travel long distances and are reflected by objects effectively.

111. **(c)** Fringe width in YDSE is:

$\beta = \frac{\lambda D}{d}$

• In a medium of refractive index μ, wavelength becomes λ/μ.

• Therefore new fringe width becomes:

$\beta' = \frac{\beta}{\mu}$

112. **(b)** Einstein photoelectric equation:

$E = \phi + eV_0$

Given:

• Photon energy $E = 3.2eV$

• Stopping potential $V_0 = 1.5$ V

So, $\phi = 3.2 - 1.5 = 1.7eV$

113. **(c)** Nuclear forces are not always attractive; at very short distances they become repulsive.

114. **(d)**Based on Lenz's Law, here is the short solution:

(a) Original Field: Using the Right-Hand Thumb Rule, the current I in the wire produces a magnetic field directed out of the page through the loop.

(b) Change in Flux: If current I increases, the outward magnetic flux through the loop also increases.

(c) Induced Field: To oppose this increase, the loop induces a magnetic field directed into the page.

(d) Induced Current: To create an inward field, the current must flow clockwise (Right-Hand Rule for loops). Following the loop labels clockwise, the direction is a → b → c.

115. **(d)**• Current leads voltage by $\pi/4$, so the circuit is capacitive.

For RC series circuit:

$\tan\phi = \frac{X_c}{R}$

Given $\phi = \pi/4$,

$\tan\frac{\pi}{4} = \frac{X_c}{R} = 1$

So,$X_C = R$

• X is a capacitor and $X_C = R$

116. **(c)** For a concave mirror, radius of curvature of reflected wavefront becomes equal to focal length:

$f = \frac{R}{2}$

117. **(b)** de Broglie wavelength:

$\lambda = \frac{h}{\sqrt{2mK}}$

For same kinetic energy, $\lambda \propto \frac{1}{\sqrt{m}}$

Mass of alpha particle $= 4m_p$

So, $\frac{\lambda_p}{\lambda_a} = \sqrt{\frac{4m_p}{m_p}} = 2$

118. **(c)** Second excited state means $n = 3$.

Energy of hydrogen atom:

$E_n = -\frac{13.6}{n^2}eV$

For $n = 3$.

$E_3 = \frac{13.6}{9} \approx -1.51eV$

119. **(a)** Binding energy per nucleon:

Binding energy per nucleon $= \frac{21u}{7} = 3u$

120. **(a)** PN junction diode with 0.5 V battery and 100Ω resistor

• Threshold voltage of diode = 0.7V.

• Applied voltage = 0.5 V, which is less than threshold.

• This means the diode is forward biased, but it will not conduct until the applied voltage exceeds 0.7 V .

• Therefore, the current in the circuit = 0 A.

121. **(a)** So, Both Assertion (A) and Reason (R) are true, and Reason (R) is the correct explanation of Assertion (A).

• In series circuit, current through all bulbs is same.

• Power consumed:

$P = I^2R$

• Resistance of bulb:

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

• Lower wattage bulb has higher resistance, so 50 W bulb consumes maximum power in series.

122. **(d)** • Assertion (A) is false, but Reason (R) is false.

• Torque on current loop:

$\tau = nBIA\sin\theta$

• For same wire length, circular loop encloses maximum area.

• Therefore circular loop experiences greater torque, not square loop.

123. **(a)** So, Both Assertion (A) and Reason (R) are true, and Reason (R) is the correct explanation of Assertion (A).

• In n-type semiconductor, electrons are majority carriers.

• Donor atoms donate electrons and become positively ionised.

• Total positive and negative charges balance, so crystal remains electrically neutral.

124. Two identical dipoles in the $x - y$ plane

• On the y-axis: dipole with $+q$ at $(0, a)$ and $-q$ at $(0, -a)$.

• On the x-axis: dipole with $-q$ at $(-a, 0)$ and $+q$ at $(+a, 0)$.

• At the origin O, each dipole produces an electric field along its axis.

For a dipole, field at the midpoint (origin here) is directed from $+q$ to $-q$ along the dipole axis, with magnitude:

$E = \frac{2kq}{a^2}$

• Dipole along y-axis → field along negative y-direction.

• Dipole along x-axis → field along negative x-direction.

Thus, net field at O is:

$\vec{E} = \frac{2kq}{a^2}(-\hat{i} - \hat{j})$

Magnitude:

$|\vec{E}| = \frac{2kq}{a^2}\sqrt{2}$

Direction: along the line making 45° with negative x-and y-axes (southwest direction).

Correct answer: Net field magnitude $= \frac{2\sqrt{2}kq}{a^2}$, direction = towards southwest $(-x, -y)$. Learn more about electric dipole fields.

125. EMF vs Terminal Potential Difference (TPD)

• EMF: The work done per unit charge by the cell in driving charges around the circuit (open circuit voltage).

• Terminal potential difference: The voltage across the terminals when current flows, less than EMF due to internal resistance.

Differences:

(1) EMF is measured when no current flows; TPD is measured when current flows.

(2) EMF ≥ TPD (because TPD = EMF - Ir , where r = internal resistance).

Precaution:

• Do not draw excessive current from the cell, as it increases voltage drop across internal resistance and reduces efficiency.

126. **(A)** Case in which potential energy is minimum

For magnetic dipoles, potential energy is minimum when the dipoles are aligned parallel to the magnetic field produced by each other.

• In Case 2, needle Q is placed on the axial line of P and both magnetic moments point along the y-axis.

• This is a stable configuration with minimum potential energy.

Potential energy is minimum in Case 2.

(B) Case in which P and Q are not in equilibrium

• In Case 1,Q is placed on the equatorial line of P.

• Magnetic field due to P at $(a, 0)$ is along negative y-axis, while magnetic moment of Q is along x-axis.

• Since magnetic moment and magnetic field are perpendicular, a torque acts on Q.

$\tau = \vec{m} \times \vec{B}$

• Hence the system is not in equilibrium.
P P and Q are not in equilibrium in Case 1.

127. **(A)** Displacement current

• Displacement current is the current associated with changing electric field between capacitor plates.

$$I_d = \varepsilon_0 \frac{dt_\mu}{dt}$$

• Difference between displacement current and conduction current

Displacement current	Conduction current
Produced due to changing electric field	Produced due to flow of charges
Exists even in vacuum or dielectric	Exists only in conducting medium
No actual movement of charges	Actual movement of electrons occurs

OR

(B) Two characteristics of electromagetic waves:
• They are transverse waves.
• They can travel through vacuum with speed of light.
Why microwaves are used in radar systems
• Microwaves can travel long distances with little atmospheric absorption.
• They are strongly reflected by aircrafts and ships, making detection easier.

128. Derivation for Planck's Constant and Work Function

According to Einstein's photoelectric equation, the maximum kinetic energy (K_{max}) of emitted photoelectrons is given by:

$$\frac{1}{2} m v_m^2 = \frac{hc}{\lambda} - \phi$$

Where:
• m = mass of an electron
• v_m = maximum speed of photoelectrons
• h = Planck's constant
• c = speed of light
• λ = wavelength of incident radiation
• ϕ = work function of the surface

Rearranging the equation to express v_m^2 in terms of $\frac{1}{\lambda}$:

$$v_m^2 = \left(\frac{2hc}{m}\right)\frac{1}{\lambda} - \frac{2\phi}{m}$$

Comparing this with the equation of a straight line, $y = mx + c$:
(1) Planck's Constant (h): The slope of the graph is equal to $\tan\theta$.

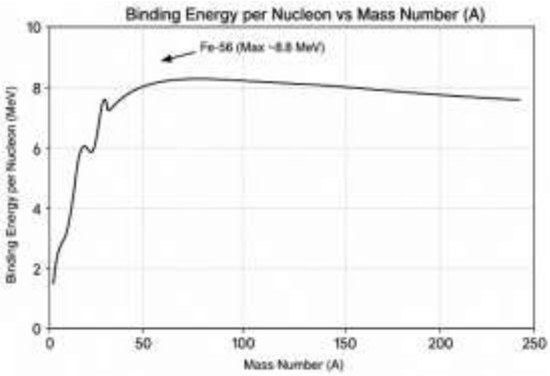
$$\text{Slope } = \tan\theta = \frac{2hc}{m} \Rightarrow h = \frac{m\tan\theta}{2c}$$

(2) Work Function (ϕ) : At the X-intercept, the maximum velocity $v_m^2 = 0$. Let this intercept value on the $\frac{1}{\lambda}$ axis be $\frac{1}{\lambda_0}$ (threshold frequency parameter).

$$0 = \left(\frac{2hc}{m}\right)\frac{1}{\lambda_0} - \frac{2\phi}{m} \Rightarrow \phi = \frac{hc}{\lambda_0} = hc \times (\text{X-intercept })$$

129. Binding Energy per Nucleon Curve and Nuclear Fission

Here is the graph showing the variation of binding energy per nucleon with mass number A:



Explanation of Energy Release in Nuclear Fission:
(1) Lower Binding Energy of Heavy Nuclei: For heavy nuclei with a mass number A > 170 (such as Uranium-238), the binding energy per nucleon is relatively lower (around 7.6 MeV) due to increased electrostatic repulsion between protons.
(2) Splitting into Lighter Fragments: During nuclear fission, a heavy unstable nucleus splits into two medium-sized daughter nuclei whose mass numbers sit closer to the peak region of the curve ($A \approx 50$ to 100), like Barium and Krypton.
(3) Gain in Stability and Energy Release: Because these intermediate daughter fragments have a higher binding energy per nucleon (around 8.5 MeV), their nucleons are much more tightly bound. The difference in total binding energy between the parent and daughter states is released outward as kinetic energy of the fragments and radiation.

130. **(A)** Electrostatic potential energy of a system of charges is:

$$U=\frac{1}{4\pi\varepsilon_0}\sum\frac{q_iq_j}{r_{ij}}$$

Here charges $q, 2q, -3q$ are placed at the vertices of an equilateral triangle of side a.
Potential energy between pairs:
(1) Between q and 2q :

$$U_1=\frac{1}{4\pi\kappa_a}\frac{2q^2}{a}$$

(2) Between 2q and −3q.

$$U_2=\frac{1}{4\pi\varepsilon_0}\frac{-6q^2}{a}$$

(3) Between q and −3q :

$$U_3=\frac{1}{4\pi\varepsilon_0}\frac{-30^2}{a}$$

• Total potential energy:

$$U=\frac{1}{4\pi\varepsilon_0}\frac{(2-6-3)q^2}{a}$$

$$U=-\frac{7q^2}{4\pi\varepsilon_0 a}$$

OR

(B) When two conducting spheres are connected by a wire, their potentials become equal.
Let final charges be Q_1 and Q_2.
Condition of equal potential:

$$\frac{Q_1}{r_1}=\frac{Q_2}{r_2}$$

Also, charge is conserved:

$$Q_1+Q_2=q_1+q_2$$

Solving.

$$Q_1=\frac{r_1}{r_1+r_2}(q_1+q_2)$$

$$Q_2=\frac{r_2}{r_1+r_2}(q_1+q_2)$$

131. Magnetic field at centre of a circular loop:

$$B = \frac{\mu_0 I}{2R}$$

Field due to loop A at its centre

$$B_A = \frac{\mu_0(3)}{2(3)} = \frac{\mu_0}{2}$$

Field due to loop B at centre of A

Distance between loops = 4 m

Field on axis of circular loop:

$$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}$$

Substituting $I = 2A, R = 3m, x = 4m$:

$$B_B = \frac{\mu_0(2)(9)}{2(9+16)^{3/2}}$$

$$= \frac{18\mu_0}{2(25)^{3/2}}$$

$$= \frac{18\mu_0}{250} = \frac{9\mu_0}{125}$$

Since currents are opposite, fields oppose each other.

$$B_{net} = \frac{\mu_0}{2} - \frac{9\mu_0}{125}$$

$$= \frac{125\mu_0 - 18\mu_0}{250} = \frac{107\mu_0}{250} \text{ T}$$

$$B_{net} = \frac{107\mu_0}{250} \text{ T}$$

132. Induced emf vs rate of change of current

(A) • The slope of the emf vs $\frac{df}{dt}$ graph represents inductance (L).

• Line X has a steeper slope than line Y, meaning greater inductance.

• An iron core increases inductance compared to an air core.

Therefore, X is the iron-cored solenoid because it has higher inductance.

Learn more about iron vs air core solenoids.

(B) Expression for self-inductance of a long solenoid:

$$L = \mu_0 \mu_r \frac{N^2 A}{L}$$

where

• N = number of turns,

• A = cross-sectional area,

• L = length of solenoid,

• μ_0 = permeability of free space,

• μ_r = relative permeability of core.

See self inductance of solenoid.

133. AC circuit problems

(A) Resistor $R = 30\Omega$, capacitor $C = \frac{250}{n}\mu F$, source $V = 200$ V, frequency $f = 50$ Hz.

Capacitive reactance:

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$$C = \frac{250}{\pi} \times 10^{-6} \text{ F}, f = 50 \text{ Hz}$$

$$X_C = \frac{1}{2\pi \cdot 50 \cdot \frac{250}{2} \times 10^{-6}} = \frac{1}{25 \times 10^{-3}} = 40\Omega$$

Impedance:

$$z = \sqrt{R^2 + X_C^2} = \sqrt{30^2 + 40^2} = \sqrt{900 + 1600} = \sqrt{2500} = 50\Omega$$

(i) Current :

$I = \frac{V}{Z} = \frac{200}{50} = 4A$

(ii) Voltage drops:

• Across resistor: $V_h = IR = 4 \times 30 = 120$ V

• Across capacitor: $V_C = IX_C = 4 \times 40 = 160$ V

(iii) Algebraic sum paradox:

• $V_R + V_C = 280\text{ V} > 200$ V.

• But voltages are not in phase; they are at right angles (resistive vs capacitive).

• True source voltage is vector sum:

$$V = \sqrt{V_R^2 + V_C^2} = \sqrt{120^2 + 160^2} = \sqrt{40000} = 200\text{ V}$$

Paradox resolved: voltages add vectorially, not algebraically.

See AC series RC circuit.

OR

(B) Series LCR circuit: $R = 20\Omega, L = 2H, C = 50\mu F, V = 200$ V.

(i) At resonance:

$X_L = X_C, Z = R$

$I = \frac{V}{R} = \frac{200}{20} = 10$ A

(ii) Average power:

$P = VI\cos\phi = VI$ ($\phi = 0$ at resonance)

$P = 200 \times 10 = 2000$ W

(iii) Potential drop across capacitor:

$V_C = IX_C$

At resonance:

$X_C = \frac{1}{\omega C}, \omega = \frac{1}{\sqrt{LC}}$

$$\omega = \frac{1}{\sqrt{2 \cdot 50 \times 10^{-6}}} = \frac{1}{\sqrt{1 \times 10^{-4}}} = 100\text{rad/s}$$

$$X_C = \frac{1}{100 \cdot 50 \times 10^{-6}} = \frac{1}{5 \times 10^{-3}} = 200\Omega$$

$V_C = IX_C = 10 \times 200 = 2000$ V

134. **(A) (i)** Type of Fringe for a Phase Difference of 5π

• Answer: A bright fringe (specifically, the 2 nd secondary maximum) will be formed.

• Explanation:

In single-slit diffraction, the phase difference (ϕ) for minima (dark fringes) is given by even multiples of π :

$\phi = 2n\pi$ $(n = 1,2,3, \ldots)$

The phase difference (ϕ) for secondary maxima (bright fringes) is given by odd multiples of π :

$\phi = (2n + 1)\pi$ $(n = 1,2,3, \ldots)$

Since the given phase difference is $\phi = 5\pi$ (an odd multiple of π where $n = 2$), it corresponds to a bright fringe.

(ii) Slit Width (a) Calculation

• Formula:

• Angular width of the central maximum in single-slit diffraction: $2\theta = \frac{2\lambda}{a}$

• Angular width of a single interference fringe in double-slit: $\theta_0 = \frac{\lambda}{d}$

• Calculation:

The question states that 8 interference maxima must fit entirely inside the central diffraction maximum:

$8 \times \theta_0 = 2\theta$

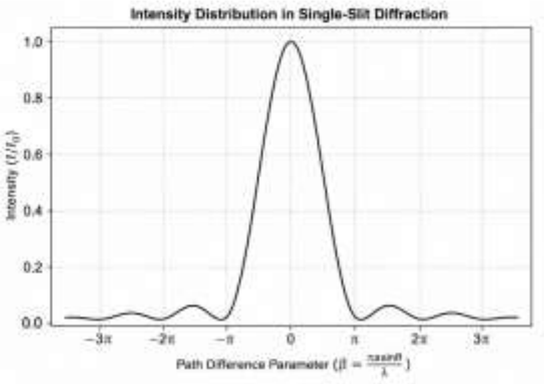
$8\left(\frac{\lambda}{d}\right) = \frac{2\lambda}{a}$

$\frac{8}{d} = \frac{2}{a} \Rightarrow a = \frac{2d}{8}$

$a = \frac{d}{c}$

(iii) Intensity Distribution Curve for Single-Slit Diffraction

• The intensity is maximum at the center (central maximum) and drops off rapidly for subsequent secondary maxima:



OR

(B) (i) Given:

$SS_2 - SS_1 = \frac{\lambda}{4}$

For constructive interference at P :

$(SS_2 - SS_1) + (S_2P - S_1P) = n\lambda$

$S_2P - S_1P = n\lambda - \frac{\lambda}{4}$

For destructive interference:

$(SS_2 - SS_1) + (S_2P - S_1P) = \frac{(2n+1)\lambda}{2}$

$S_2P - S_1P = \frac{(2n+1)\lambda}{2} - \frac{\lambda}{4}$

(ii) • Central fringe becomes white.

• A few coloured fringes are seen on both sides.

• Further fringes overlap and become indistinct.

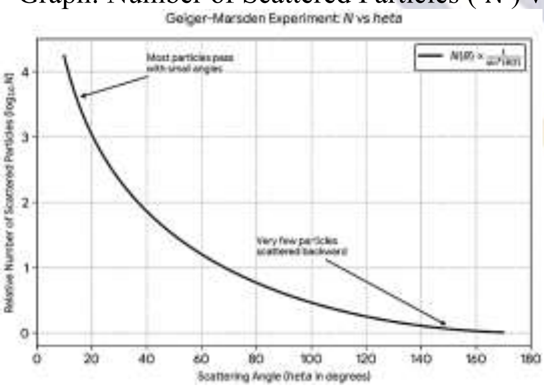
135. Geiger-Marsden Experiment (Alpha-Particle Scattering)

• Brief Explanation

In 1911, H. Geiger and E. Marsden (under the guidance of Ernest Rutherford) directed a narrow beam of high-energy α-particles (Helium nuclei, He^{2+}) from a radioactive source (Bismuth-214) at a very thin gold foil (about 2.1×10^{-7} m thick).

The scattered α-particles were detected using a rotatable zinc sulfide (ZnS) screen and a microscope, which produced small flashes of light (scintillations) whenever struck.

• Graph: Number of Scattered Particles (N) vs. Scattering Angle (θ)



• Main Conclusions Inferred From the Plot

The plot shows that while the vast majority of **α**-particles suffer almost zero deflection, an incredibly tiny fraction (about 1 in 8000) bounce backward at angles greater than 90°. From this distribution, Rutherford inferred the following structural truths about the atom:

(1) Empty Space: Most of the atom's volume is completely empty space, since most **α** particles pass straight through undeflected.

(2) The Nucleus Exists: The entire positive charge and practically all the mass of the atom are concentrated into an extremely small, dense region at the center, called the nucleus.

(3) Nuclear Dimensions: Since only a rare head-on collision causes a particle to reverse direction, the nucleus must occupy a minute fraction of the overall atomic volume (about 10^{-15} m compared to the atom's 10^{-10} m).

136. **(A) (i)** Mobility of Electrons

• Definition: Mobility (μ) is defined as the magnitude of the drift velocity (v_d) per unit electric field (E).
Mathematically: $\mu = \frac{b_d}{E}$.

• SI Unit: $m^2V^{-1}s^{-1}$.

(ii) Wire of Varying Cross-section

• Electric Field: For a steady current I, the field is $E = \frac{V}{l} = \frac{IB}{l}$. Since $R = \rho\frac{l}{A}$, we get $E = \frac{I\rho}{A}$. As the wire widens from A to B (increasing area A), the electric field decreases.

• Drift Velocity: From $I = neAv_d$, we have $v_d = \frac{l}{ncA}$. As area A increases, the drift velocity decreases.

(iii) Circuit Calculation

(1) Simplify Right Branch: The 10Ω (top-mid) and 10Ω (bottom-mid) are in series $= 20\Omega$

(2) Parallel Combination: That 20Ω is in parallel with the 30Ω resistor.

$$R_p = \frac{30 \times 20}{30 + 20} = \frac{600}{50} = 12\Omega$$

(3) Total Resistance: The 12Ω equivalent is in series with the top 10Ω and the right 14Ω.

$R_{eff} = 10 + 12 + 14 = 36\Omega$

(4) Current: $I = \frac{V}{R} = \frac{6\text{ V}}{36\Omega} = \frac{1}{6}$ A ≈ 0.167 A.

OR

(B) (i) Electrical Conductivity

Definition: Conductivity (σ) is the reciprocal of electrical resistivity. It represents a material's ability to allow the flow of electric current.

$$\sigma = \frac{1}{\rho}$$

SI Unit: Sm^{-1} (Siemens per meter) or $\Omega^{-1}m^{-1}$.

(ii) Internal Resistance Comparison

To draw a high current $\left(I = \frac{E}{R_1 r}\right)$:

(1) Low-voltage battery: Since E is small, the internal resistance r must be extremely low (e.g., lead-acid accumulators) to allow high current.

(2) High-voltage battery: Since E is already high, the battery can afford to have a higher internal resistance and still provide high current safely without short-circuiting easily.

(iii) Energy Calculation

(1) Net EMF: The 10 V and 4 V batteries are in opposition.

• $E_{net} = 10 - 4 = 6$ V.

(2) Total Resistance: All resistors are in series.

• $R_s = 1 + 2 + 6 + 3 = 12\Omega$.

(3) Circuit Current:

• $I = \frac{E_{act}}{R_,} = \frac{6}{12} = 0.5$ A.

(4) Energy Supplied in 1 minute (t = 60 s):

The "supply" battery is the 10 V one. Energy $E = V \times I \times t$.

• Energy from 10 V battery: $10 \times 0.5 \times 60 = 300$ J.

• Energy absorbed by 4 V battery: $4 \times 0.5 \times 60 = 120$ J.

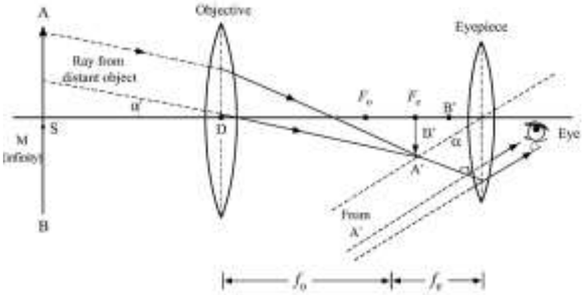
• Net Energy supplied to the circuit: $E_{net} \times I \times t = 6 \times 0.5 \times 60 = 180$ J.

137. **(A) (i)** • In an astronomical telescope, the objective lens forms an intermediate real image, and the eyepiece lens magnifies it.

• The object (e.g., a distant star) is placed far away, so the incoming rays are parallel.

• These parallel rays first pass through the objective lens, which converges them to form a real, inverted image at its focal point (F_o).

• The eyepiece lens is then positioned such that this intermediate image lies at its focal point. As the eyepiece lens diverges the rays, they appear to originate from infinity, creating the final image that is seen by the observer.



Magnifying power (Angular Magnification):
(1) When the image is formed at a finite distance (e.g., at distance D):
The magnifying power is given by the formula:

$$M=-\frac{f_o}{f_e}\left(1+\frac{f_e}{D}\right)$$

This formula takes into account the image formed at a distance D (closer than infinity).
(2) When the image is formed at infinity (which is typical for astronomical telescopes):
The magnifying power simplifies to:

$$M=-\frac{f_o}{f_e}$$

This is the standard expression for magnifying power when the final image is at infinity.
(ii) Image by Lens Combination
The final image is located 54 cm to the left of lens L_2 (or 9 cm to the left of lens L_1) and has a height of 4 cm .
(1) Image by Lens L_1 :
Given: $f_1=+24\text{ cm}, u_1=-36\text{ cm}$.
Using lens formula $\frac{1}{v_1}-\frac{1}{u_1}=\frac{1}{f_1}$:

$$\frac{1}{v_1}=\frac{1}{24}+\frac{1}{-36}=\frac{3-2}{72}=\frac{1}{72}\Longrightarrow v_1=72\text{ cm}$$

Magnification $m_1=\frac{v_1}{u_1}=\frac{72}{-36}=-2$.
(2) Object for Lens L_2 :
The image I_1 is 72 cm to the right of L_1. Since L_2 is 45 cm from L_1, the object distance for L_2 is:
$u_2=v_1-d=72-45=+27\text{ cm}$ (virtual object)
(3) Final Image by L_2 :
Given: $f_2=-18\text{ cm}, u_2=+27\text{ cm}$.

$$\frac{1}{v_2}=\frac{1}{-18}+\frac{1}{27}=\frac{-3+2}{54}=-\frac{1}{54}\Longrightarrow v_2=-54\text{ cm}$$

Magnification $m_2=\frac{v_2}{u_2}=\frac{-54}{27}=-2$.
(4) Final Height:
Total magnification $M=m_1\times m_2=(-2)\times(-2)=4$.
Height $h_i=M\times h_o=4\times 1=4\text{ cm}$.

OR

(B) (i) Optical Fibre and Light Pipe
Working Principle:
Optical fibers work on the principle of Total Internal Reflection (TIR). A fiber consists of a core (higher refractive index) and a cladding (lower refractive index). When light enters the core at an angle greater than the critical angle, it undergoes repeated total internal reflections, traveling along the fiber with minimal energy loss.
Use of a Light Pipe:
A light pipe is commonly used in endoscopy to illuminate and view internal organs in the human body.
(ii) Prism problem
Given:
• Angle of incidence.
$i=60^\circ$
• Prism angle,
$A=60^\circ$
Since the ray passes symmetrically through the prism:

$i = e$

And $r_1 = r_2 = \frac{A}{2}$

$r = \frac{60^\circ}{2} = 30^\circ$

Using prism formula at minimum deviation:

$\delta_m = 2i - A$

$\delta_m = 2(60^\circ) - 60^\circ$

$\delta_m = 60^\circ$

Refractive index of prism

Using Snell's law:

$\mu = \frac{\sin i}{\sin r}$

$\mu = \frac{\sin 60^\circ}{\sin 30^\circ}$

$\mu = \frac{\frac{\sqrt{3}}{2}}{\frac{1}{2}}$

$\mu = \sqrt{3} \approx 1.73$

138. **(A)(i)** • Doping germanium with antimony (pentavalent impurity) forms an n-type semiconductor.

• One extra electron becomes free for conduction.

• Donor energy level is created just below conduction band, so conductivity increases.

(ii) Formation of $p - n$ junction

(1) Diffusion:

• Majority carriers diffuse across junction due to concentration difference.

(2) Drift:

• Electric field of depletion region causes drift of carriers opposite to diffusion.

(iii) Effect on depletion layer

(1) Forward biasing:

• Depletion layer width decreases.

(2) Reverse biasing:

• Depletion layer width increases.

OR

(B) (i) Full-wave rectifier

• It uses two p-n junction diodes and a centre-tapped transformer.

• During positive half cycle, one diode conducts.

• During negative half cycle, the other diode conducts.

• Current through load remains in same direction in both half cycles, giving pulsating DC output.

(ii) V-I characteristics of p-n junction diode

• In forward bias, current increases rapidly after cut-in voltage.

• In reverse bias, only very small reverse current flows till breakdown.

Why suitable for rectification:

• Diode allows current mainly in one direction and blocks it in opposite direction.

(iii)• Carbon has larger band gap ($\approx 5.5\text{eV}$), so electrons cannot easily move to conduction band. Hence it is an insulator.

• Silicon has smaller band gap ($\approx 1.1\text{eV}$), so some electron can move to conduction band at room temperature, making it a semiconductor.

139. **(A)** Variation of $|\vec{E}|$ with distance r for a conducting shell

For a uniformly charged conducting shell of radius R :

• Inside ($r < R$) : $|\vec{E}| = 0$

• At the surface ($r = R$): $|\vec{E}| = \frac{kQ}{R^2}$ (Maximum)

• Outside ($r > R$): $|\vec{E}| = \frac{kQ}{r^2}$ (Follows inverse square law)

Graph Description: The graph starts at the origin and stays at 0 on the x -axis until r = R. At r = R, there is a vertical jump to the maximum value, followed by a parabolic curve decreasing towards 0 as r approaches 3R.

(B) Ratio of charges $\frac{Q_1}{Q_2}$

The potential V due to a point charge is given by $V = \frac{kQ}{r} = kQ \cdot \left(\frac{1}{r}\right)$.

In a graph of V ∨ v$\frac{1}{r}$, the slope represents kQ.

- $\text{Slope}_1 = \tan(60^\circ) = kQ_1 \Rightarrow \sqrt{3} = kQ_1$
- $\text{Slope}_2 = \tan(30^\circ) = kQ_2 \Rightarrow \frac{1}{\sqrt{3}} = kQ_2$

Dividing the two:

$$\frac{Q_1}{Q_2} = \frac{\tan(60^\circ)}{\tan(30^\circ)} = \frac{\sqrt{3}}{1/\sqrt{3}} = 3$$

(C) Potential Energy of the Dipole

The potential energy U is given by $U = -pE\cos\theta$.

Given: $p = 6 \times 10^{-7} C \cdot m, E = 10^4$ N/C, and they are parallel ($\theta = 0^*$).

$U = -(6 \times 10^{-7})(10^4)\cos(0^\circ)$

$U = -6 \times 10^{-3}$ J

OR

(C) Work Done in Rotation

Work done W is the change in potential energy: $W = U_f - U_i = -pE(\cos\theta_2 - \cos\theta_1)$

• Initial position: Perpendicular ($\theta_1 = 90^\circ$)

• Final position: Antiparallel ($\theta_2 = 180^\circ$)

$W = -pE(\cos 180^\circ - \cos 90^\circ)$

$W = -pE(-1 - 0) = pE$

140. **(A)** Effect of increase in wavelength on power of lens

As wavelength increases, refractive index μ of lens material decreases.

From lens maker formula:

$$P = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Power depends directly on (μ − 1).

Hence, when wavelength increases, power decreases.

(B) Finding refractive index μ

For a convex lens:

$R_1 = +R, R_2 = -R$

Lens maker formula:

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Given:

f = R

Substituting:

$$\frac{1}{R} = (\mu - 1)\left(\frac{1}{R} - \left(-\frac{1}{R}\right)\right)$$

$$\frac{1}{R} = (\mu - 1)\frac{2}{R}$$

$1 = 2(\mu - 1)$

$2\mu = 3$

$$\mu = \frac{3}{2} = 1.5$$

(C) Focal length of concave lens in water

Given:

• In air,

$f_1 = -20$ cm

• Refractive index of lens:

$$\mu_l = \frac{3}{2}$$

• Refractive index of water:

$$\mu_w = \frac{4}{3}$$

Relative refractive index in water:

$$\mu_{rel} = \frac{\mu_l}{\mu_w} = \frac{3/2}{4/3} = \frac{9}{8}$$

Using lens maker relation:

$$\frac{1}{f} \propto (\mu_{rel} - 1)$$

So,

$$\frac{f_w}{f_a} = \frac{\mu_l - 1}{\mu_{rel} - 1}$$

$$\frac{f_w}{20} = \frac{\frac{3}{2} - 1}{\frac{9}{8} - 1}$$

$$= \frac{\frac{1}{2}}{\frac{1}{8}} = 4$$

$$f_w = -80 \text{ cm}$$

OR

(C) Given:

Power:

$$P = 5D$$

Focal length:

$$f = \frac{1}{P} = \frac{1}{5} \text{ m} = 20 \text{ cm}$$

Image is erect and magnified:

$$m = +3$$

For lens:

$$m = \frac{v}{u}$$

$$v = 3u$$

Lens formula:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Substitute $v = 3u$:

$$\frac{1}{20} = \frac{1}{3u} - \frac{1}{u}$$

$$\frac{1}{20} = \frac{1-3}{3u} = \frac{-2}{3u}$$

$$u = -\frac{40}{3} \text{ cm}$$

$$u \approx -13.3 \text{ cm}$$

Then,

$$v = 3u = -40 \text{ cm}$$

141. **(a)** Given:

$\theta = 30^\circ, E = 2 \times 10^5$ N/C, $\tau = 8 \times 10^{-3}$Nm and $2a = 2$ cm $= 0.02$ m

To find: Charge q = ?

We know that, $\tau = pE\sin\theta$

$= (q \times 2a)E\sin\theta$ …. ($\because p = q \times 20$)

$$q = \frac{\tau}{2a.E\sin\theta}$$

$$q = \frac{8 \times 10^{-3}}{0.02 \times 2 \times 10^5 \times \sin 30^\circ}$$

$= 400 \times 10^{-3} \times 10^{-5}$

$q = 4\mu C$

142. **(c)** Given $I_1 = I_2 = 3$ A, d = 2 m, the current is flowing in the same direction, Now, $\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi d}$

$$= \frac{4\pi \times 10^{-7} \times 3 \times 3}{2\pi \times 2}$$
$$= 9 \times 10^{-7}\ \text{N/m}$$
$$\frac{F}{l} = 9 \times 10^{-7}\ \text{N/m}$$

143. **(a)** It is diamagnetic, meaning it weakly opposes magnetic fields. This gives it a magnetic permeability slightly less than that of free space (μ_0).

144. **(d)**Given, no. of turns $(N) = 100$, side of square $= 10$ cm Rate of change of magnetic field $\frac{dB}{dt} = 1\frac{T}{s}$

$$\therefore \text{ Emf of coil } = NA\frac{d\phi}{dt}$$
$$= 100 \times (0.1 \times 0.1) \times 1$$
$$\varepsilon = 1\ \text{V}$$

145. **(a)** The electromagnetic spectrum is the dispersion of electromagnetic radiation based on energy. Gamma rays, x -rays, ultraviolet, visible, infrared, microwaves, and radio waves are the seven main categories that it falls under. These zones are given in decreasing energy and frequency and rising wavelength order. Among the main types of electromagnetic radiation, gamma waves have the highest frequencies (most energetic) and shortest wavelengths, whereas radio waves have the lowest frequencies (least energetic) and longest wavelengths. Therefore, the smallest wavelength is that of gamma rays.

146. **(c)** When the screen is moved away ' D ' increases and we know $\beta = \frac{\lambda D}{d}$

So, if D increases, fringe-width (β) also increases and angular separation $\left(\frac{\lambda}{d}\right)$ remains the same.

147. **(b)** The energy of a photon of wavelength λ is $\frac{\mathbf{hc}}{\boldsymbol{\lambda}}$.

The energy of a photon is given by,

$E = h\nu$

So, $E = \frac{hc}{\lambda}$

148. **(d)** Given, $A_1 = 64,\ A_2 = 125$

$$R = R_0 A^{1/3}$$
$$\text{Density } = \frac{\text{Atomic Mass}}{\text{Volume}} = \frac{A}{\frac{4}{3}\pi R^3}$$
$$= \frac{A}{\frac{4}{3}\pi R^3} = \frac{A}{\frac{4}{3}\pi (R_0 A^{1/3})^3}$$
$$= \frac{A}{\frac{4}{3}\pi R_0^3 A}$$
$$\rho = \frac{1}{\frac{4}{3}\pi R_0^3}$$
$$\frac{\rho_1}{\rho_2} = \frac{\frac{4}{3}\pi R_0^3}{\frac{4}{3}\pi R_0^3} = 1$$

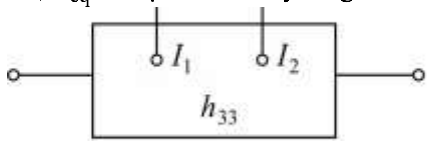
It is independent of mass number.

149. **(d)** During the formation of a p-n junction diffusion current remains almost constant but the drift current increases till both currents become equal.

150. **(a)** The correct scale is used to create the energy diagram, which displays the various energy levels.
The largest energy difference occurs during the change from state 3 to state 1 . The first jump would be the most energetic and provide the strongest photon emission.

151. **(c)** When the capacitors are connected in parallel the equivalent capacitance is given by

$C_{eq} = C_1 + C_2 + C_3$
in series $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$
here $C_1 = C_2 = C_3 = 4\mu F$
$C_{eq} = 6\mu F$
So, $C_{eq} = 6\mu$ F can only be get if two capacitors are connected in series with the third one in parallel as shown.



$$C_{eq} = \frac{4 \times 4}{4 \times 4} + 4$$
$= 2 + 4 = 6\mu$ F

152. **(d)** de-Broglie wavelength is the wavelength that is connected to an object in relation to its momentum and mass. Typically, the force of a particle is inversely proportional to its de-Broglie wavelength.
A photon's momentum is determined by:
$P = \frac{E}{c} = \frac{h}{\lambda}$ where E is the energy of the photon, c is the speed of light in vacuum, h is Planck's constant and λ is the de-Broglie wavelength.
According to de-Broglie, $p = \frac{h}{\lambda}$ or $p \propto \frac{1}{\lambda}$.
By this relation, we can conclude that the linear momentum of a photon is inversely proportional to the de-Broglie wavelength. The graph of p vs λ shall be a rectangular hyperbola.

153. **(a)** Series LCR circuit
• Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$.
• As frequency increases:
• At low frequency, X_C dominates → impedance decreases.
• At resonance, $X_L = X_C$ → impedance minimum.
• At high frequency, X_L dominates → impedance increases.

154. **(b)** • Huygens principle
• Secondary wavelets are not equally strong in both directions.
• The amplitude is maximum in the forward direction and zero in the backward direction (explains why we see forward propagation of waves).

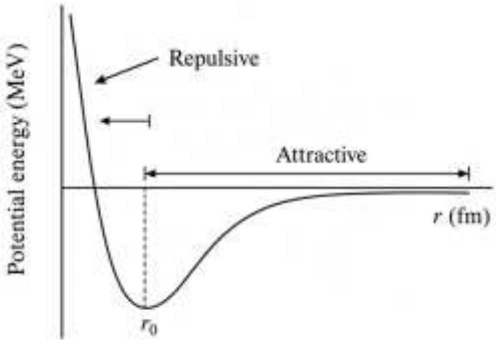
155. **(a)** • Bohr model radius
• Radius of nth orbit:
$$r_n = n^2 \cdot \frac{h^2}{4\pi^2 me^2} \cdot \frac{1}{Z}$$
So $r_n \propto n^2$.

156. **(a)** Intrinsic semiconductor
• Assertion (A): Resistance decreases with temperature → True.
• Reason (R): With rise in temperature, more electrons jump to conduction band, increasing both electron and hole concentration → True.
• The reason correctly explains the assertion.
So, Both A and R are true, and R is the correct explanation of A .

157. **(c)** Equivalent resistance of given network
• Assertion (A): Equivalent resistance between A and B is $2R$.
• Reason (R): All resistors are connected in parallel → False (they are in mixed series-parallel).
• From calculation: Equivalent resistance really comes out to $2R$.

158. **(c)** Deflecting torque on current loop
• Torque is given by vector product:
$\vec{t} = \vec{m} \times \vec{B}$
• If plane of loop ⊥ magnetic field, then $\vec{m} || \vec{B}$ → torque $= 0$. Assertion is true.
• Reason (R): It says torque is given by dot product $(\vec{m} \cdot \vec{B})$ → False.

159. The potential energy of a pair of nuclear as a function of their separation:



r_0 is the distance at which potential energy is minimum.
For a separation greater than r_0, the force is attractive and for separations less than r_0 the force is strongly repulsive.

160. **(A) (i)** According to the de-Broglie wavelength formula, the wavelength is inversely proportional to electron momentum. The product of mass and velocity is momentum. As a result, as the electron's velocity declines, so does its momentum. As a result, the de-Broglie wavelength of the electron will grow.

(ii) The electron's speed increases as the accelerating potential increases. The electron's momentum increases, and the wavelength decreases according to the de-Broglie wavelength formula. As a result, the de-Broglie wavelength of the electron will decrease.

OR

(B) (i) The stopping potential for a certain photosensitive surface increases as the frequency of the incident radiation increases. This is because the stopping potential is directly proportional to the frequency of the incident radiation, according to the photoelectric effect equation: $K_{max} = hf - \Phi$, where h is Planck's constant, f is the frequency of incident radiation and the metal's work function. K_{max} is the photoelectron's maximal kinetic energy. As a result, as the frequency of the input radiation increases, so does the stopping potential required to stop the photoelectrons, while the kinetic energy of the photoelectrons emitted decreases.

(ii) A decrease in incident radiation intensity would have no effect on the stopping potential of a certain photosensitive surface. This is because the stopping potential is exclusively determined by frequency rather than intensity of incident radiation. The kinetic energy of photoelectrons is determined only by the frequency of incident radiation, but the number of photoelectrons emitted from the surface is inversely proportional to the intensity of the received light. As a result, decreasing the intensity of the incident radiation would result in fewer photons being produced, but it would have no influence on their kinetic energy or stopping potential.

161. **(A)** Electromagnetic waves of wavelengths range 10^{-12} m $< \lambda < 10^{-8}$ m are known as X-rays. These are utilised in medicine as diagnostic instruments, as well as in scientific research and crystallography.

(B) Microwaves are electromagnetic waves with wavelengths of 10^{-3} m $< \lambda < 10^{-1}$ that are utilised in radar, microwave telephony, and microwave ovens, among other things.

162. **(a)** The dipole is in stable equilibrium when it is parallel to the electric field (i.e., the angle between the dipole moment and the electric field is 0°).

(b) When the dipole is aligned anti-parallel to the electric field (i.e., the angle between the dipole moment and the electric field is 180°, then the dipole is in unstable equilibrium.

For stable equilibrium ($\theta = 0^\circ$)
Potential energy $U = -pE\cos\theta$
$U = -pE$

163. **(A)** Lorentz force = Magnetic force + Electric force

$\Rightarrow \vec{F} = q(\vec{v} \times \vec{B})$
$\vec{F} = q \cdot v \cdot B\sin\theta$
when $\theta = 90^\circ$ the Lorentz force is maximum.
If $\overrightarrow{ds}$ is the instantaneous displacement of charge and $\overrightarrow{ds}$ is also perpendicular to $\vec{F}$.
Then,
$W = \vec{F} \cdot \overrightarrow{ds}$
$= \vec{F}\vec{s}\cos\theta$
$= F.s\cos 90^\circ$
$\cos 90^\circ = 0$

So, W = 0

Hence, no work is done by this force on the particle during its motion from a point $\vec{r}_1$ to point $\vec{r}_2$.

OR

(B) Magnetic field induction at P due to current I in long straight wire AB is

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

It acts perpendicular to the plane of the paper inward, represented by $\hat{n}$.

Lorentz force acting on the particle at P can be given by

$$\vec{F} = q(\vec{v} \times \vec{B}) = e\left(\vec{v} \times \frac{\mu_0 \cdot 2I}{4\pi d}\hat{n}\right)$$

or $\vec{F} = \frac{\mu_0 I e v}{2\pi d}(\hat{v} \times \hat{n})$

$\therefore F = \frac{\mu_0 I e v}{2\pi d}$

Acting in the plane of paper away from the wire.

For unstable equilibrium ($\theta = 180°$)

Potential Energy U = $-pE\cos\theta$

U = pE

164. **(i)** Mobility of electron $\mu = \frac{v_d}{E} = \frac{v_d l}{V}$

as $E = \frac{V}{l}$

Hence, $\mu \propto \frac{1}{V}$

(ii) If V becomes 2 V , the mobility will become half. The current density is given by

$J = nev_d$

$J = ne \cdot \frac{eV\tau}{ml}$

$J = \frac{ne^2 V\tau}{ml}$

$J \propto V$

When V become 2 V current density will become twice.

165. **(i)** Φ_2 = magnetic flux linked with coil C_2.

I_1 = current passes in coil C_1.

Lets no. of turns in coil C_1 be N_1.

No. of turns in coil C_2 be N_2.

According to Faraday's law,

$$E_{\text{ind}} = \frac{d\phi}{dt}$$

$$E_{21} = -N_2\frac{d\phi_2}{dt}$$

$$E_{21} = -N_2\frac{d}{dt}(\vec{B} \cdot \vec{A})$$

$N_2\phi_2 \propto I_1$

$N_2\phi_2 = M_{21}I_1$

M_{21} is called mutual inductance.

$$M_{21} = \frac{N_2\phi_2}{I_1}$$

(ii) Induced emf (E) $= -L\frac{dI}{dt}$

$$\frac{dI}{dt} = \frac{E}{-L}$$

$$\frac{dI_1}{dt} = -100\left(\frac{1}{L}\right)$$

Here, L is the inductance of the coil C_2.

166. **(A)** Huygens' Construction: Refraction & Snell's Law

Tracing the Refracted Wavefront:

(1) Consider a plane wavefront AB incident at an angle i on the interface separating medium $1(\mu_1)$ and medium $2(\mu_2$, where $\mu_2 > \mu_1)$.
(2) Let v_1 and v_2 be the speeds of light in the two media. Since $\mu_2 > \mu_1, v_2 < v_1$.
(3) In the time (t) it takes for point B of the wavefront to reach point C on the interface $(BC = v_1 t)$, the secondary wavelet from point A travels a distance $AD = v_2 t$ in the second medium.
(4) Draw an arc of radius $v_2 t$ from point A. The tangent plane CD drawn from C to this arc represents the refracted wavefront, making an angle r with the interface.
Verification of Snell's Law:
In $\triangle ABC: \sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$
In $\triangle ADC: \sin r = \frac{AD}{AC} = \frac{v_2 t}{AC}$
Dividing the two:
$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$
Since refractive index $\mu = \frac{c}{v}$, then $\frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$.
Thus, $\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$, which is Snell's Law.

OR

(B) Reflection by Huygens' Principle
• Let AB be the incident wavefront.
• Point $\boldsymbol{A}$ strikes the mirror first.
• In time t, point B reaches C.
Then,
$BC = vt, AD = vt$
So, $BC = AD$
From congruent triangles,
$\angle i = \angle r$
Hence, $i = r$

167. **(i)** Identification of Devices:
• Device X : Since the current lags the voltage by $\pi/2$ radians, device X is a pure inductor (L).
• Device Y : Since the current is in phase with the voltage, device Y is a pure resistor (R).
(ii) Current in Series Combination:
• Calculate Impedance of $X(X_L)$: $X_L = \frac{V}{I} = \frac{220}{0.22} = 1000\Omega$.
• Calculate Resistance of $Y(R)$: $R = \frac{V}{I} = \frac{220}{0.22} = 1000\Omega$.
• Net Impedance (Z) in series: $Z = \sqrt{R^2 + X_L^2} = \sqrt{1000^2 + 1000^2} = 1000\sqrt{2}\Omega$.
• New Current (I_{series}) :
$$I = \frac{V}{Z} = \frac{220}{1000\sqrt{2}} = \frac{0.22}{\sqrt{2}} \approx 0.156\text{A}$$

168. AC Generator
Basic Principle:
It works on the principle of Electromagnetic Induction. When a closed coil is rotated in a uniform magnetic field, the magnetic flux linked with the coil changes, inducing an electromotive force (emf) in it.
Working:
(1) A rectangular coil (armature) is rotated between the poles of a strong magnet.
(2) As the coil rotates, the angle θ between the magnetic field $\vec{B}$ and the area vector $\vec{A}$ of the coil changes continuously.
(3) This change in orientation varies the magnetic flux ($\phi = NBA\cos\theta$), which induces a current according to Faraday's Law. The direction of current reverses every halfcycle, producing an alternating current.
Expression for Instantaneous EMF:
Let N be the number of turns, A the area of the coil, B the magnetic field, and ω the angular velocity.
Magnetic flux at time t is: $\phi = NBA\cos(\omega t)$
According to Faraday's Law: $\varepsilon = -\frac{d\phi}{dt}$
$$\varepsilon = -\frac{d}{dt}(NBA\cos\omega t) = -NBA(-\omega\sin\omega t)$$

$\varepsilon = NBA\omega \sin\omega t$
Setting $\varepsilon_0 = NBA\omega$ (peak emf), the instantaneous emf is:
$\varepsilon = \varepsilon_0 \sin\omega t$

169. **(A)** Increasing Current Sensitivity

The current sensitivity of a moving coil galvanometer is the deflection per unit current ($\theta I I$. It is given by the formula $\frac{NBA}{k}$. You can increase it by:

- Increasing the number of turns (N) in the coil.
- Increasing the magnetic field (B) by using stronger permanent magnets or a soft iron core.
- Increasing the area (A) of the coil.
- Decreasing the torsional constant (k) of the suspension wire, often by using materials like phosphor bronze.

(B) Finding Galvanometer Resistance
The resistance of the galvanometer is $R_G = R_2 - 2R_1$.
(1) Set up equations for each range
A galvanometer of resistance G is converted into a voltmeter of range V by adding a series resistance R. The formula is $V = I_g(R + G)$. (1) Filo +3

- For range ($0 - V$) with $R_1 : V = I_g(R_1 + G) -$ (Equation 1)
- For range $(0 - 2V)$ with $R_2 : 2V = I_g(R_2 + G) -$ (Equation 2)

(2) Solve for G
Substitute the value of V from Equation 1 into Equation 2:
$2[I_g(R_1 + G)] = I_g(R_2 + G)$
Divide both sides by I_g :
$2R_1 + 2G = R_2 + G$
Rearrange to isolate G :
$2G - G = R_2 - 2R_1$
$G = R_2 - 2R_1$

170. **(A)(i)** Distance of Closest Approach vs. Impact Parameter

- Distance of Closest Approach (r_0) : The minimum distance from the center of the nucleus that an alpha particle reaches before it stops and reverses its direction. At this point, all its kinetic energy is converted into electrostatic potential energy.
- Impact Parameter (b): The perpendicular distance of the initial velocity vector of the alpha particle from the center of the nucleus. It determines the angle of scattering.

(ii) Calculation of Closest Approach
The distance of closest approach is approximately 5.76×10^{-14}m.
(1) Use the energy conservation principle
At the distance of closest approach (r_0), the initial kinetic energy (K) equals the potential energy:

$$K = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r_0}$$

Where q_1 (alpha particle) $= 2e$ and q_2 (gold nucleus) $= Ze$.
(2) Plug in the values

- $K = 3.95\text{MeV} = 3.95 \times 10^6 \times 1.6 \times 10^{-19}$ J
- $Z = 79$
- $\frac{1}{4\pi\varepsilon_0} \approx 9 \times 10^9 \text{Nm}^2/\text{C}^2$

$$r_0 = \frac{9 \times 10^9 \times (2 \times 79 \times (1.6 \times 10^{-19})^2)}{3.95 \times 10^6 \times 1.6 \times 10^{-19}}$$

$r_0 \approx 5.76 \times 10^{-14}$ m

OR

(B) (i) Three Postulates of Bohr Theory
(1) Electrons revolve around nucleus only in certain stable circular orbits without radiating energy.
(2) Only those orbits are allowed for which angular momentum is quantized:

$$mvr = \frac{nh}{2\pi}$$

(3) Radiation is emitted or absorbed when electron jumps from one orbit to another.
$h\nu = E_2 - E_1$
(ii) Angular Momentum in Second Orbit

According to Bohr's quantization condition:
$$L=\frac{nh}{2\pi}$$
For second orbit, $n=2$,
$$L=\frac{2h}{2\pi}=\frac{h}{\pi}$$
Using $h=6.63\times10^{-34}$ J s,
$$L=\frac{6.63\times10^{-34}}{3.14}$$
$L\approx2.11\times10^{-34}$ J s
$L=2.1\times10^{-34}$ kg m^2 s^{-1}

171. **(A) (i)** Mechanism of Drift Velocity and its Expression

In a metal, free electrons move randomly due to thermal energy. Their average thermal velocity is zero because they move in all possible directions. When an electric field (E) is applied, it exerts a force $F=-eE$ on each electron, causing it to accelerate:
$$a=\frac{F}{m}=\frac{-eE}{m}$$
As electrons accelerate, they frequently collide with the heavy metal ions. After each collision, an electron loses its acquired velocity and starts accelerating again. The average time between two successive collisions is called the relaxation time (τ).
The velocity gained by an electron in time τ is $v=u+a\tau$. Averaging this over all electrons:
Since the average initial thermal velocity (u_{avg}) is zero, the average velocity, called drift velocity (v_d), is:
$$v_d=\frac{eE}{m}\tau$$
(ii) Ratio of Drift Velocity

For two wires in series, the current (I) is the same. They also have the same diameter, meaning their cross-sectional area (A) is the same.
Using the relation $I=nAev_d$:
$$n_AAev_{dA}=n_BAev_{dB}\Longrightarrow n_Av_{dA}=n_Bv_{dB}$$
$$\frac{v_{dA}}{v_{dB}}=\frac{n_B}{n_A}$$
Given $n_A=1.5n_B$, the ratio is:
$$\frac{v_{dA}}{v_{dB}}=\frac{n_B}{1.5n_B}=\frac{1}{1.5}=\frac{2}{3}$$
OR

(B) (i) Variation of Terminal Voltage (V)

(1) V vs. R: $V=E\left(\frac{R}{R+r}\right)$. As R increases, V increases asymptotically towards E. When $R=0, V=0$; when $R\rightarrow\infty, V=E$.

(2) V vs. I: $V=E-Ir$. This is a linear relationship with a negative slope. The graph is a straight line intersecting the Y -axis (V) at E and the X -axis (I) at the short-circuit current (E/r).

(ii) Parallel Combination of Cells

Three cells with the same emf (E) connected in parallel have an equivalent emf (E_{eq}) equal to the emf of a single cell:
$$E_{eq}=E$$
The equivalent internal resistance (r_{eq}) is:
$$\frac{1}{r_{eq}}=\frac{1}{2r}+\frac{1}{3r}+\frac{1}{6r}=\frac{3+2+1}{6r}=\frac{6}{6r}=\frac{1}{r}\Longrightarrow r_{eq}=r$$
(1) Current in the circuit (I):
$$I=\frac{E_{eq}}{R+r_{eq}}=\frac{\mathrm{E}}{\mathrm{R}+\mathrm{r}}$$
(2) Terminal potential difference (V) :
$$V=I\times R=\frac{\mathrm{ER}}{\mathrm{R}+\mathrm{r}}$$
172. **(A)**

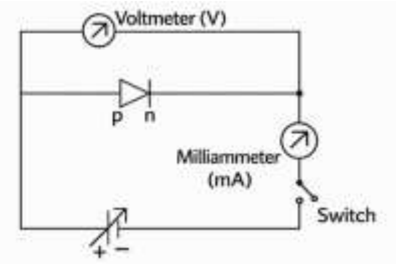


Fig-(a)

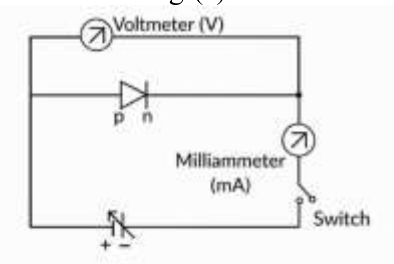


Fig-(b)

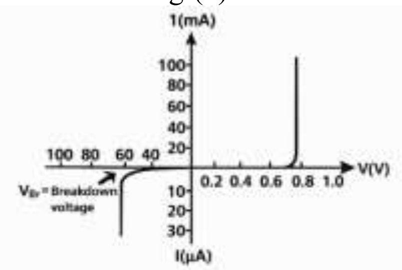


Fig-(c)

• Figures (a) and (b) depict the circuit for examining a diode's V-I properties. The value of current is noted for various voltage values. The result is a graph between C and I, as shown in Fig. (c).
It is evident from a junction diode's V-I characteristics that current can only flow through it when it is forward biassed. As a result, when alternating voltage is placed across a forward biassed diode, current only flows during a portion of the cycle.
• A lternating voltages are rectified using this characteristic.
(i) Circuit Arrangement & V-I Characteristics
• Forward Bias: Connect the p-side of the diode to the positive terminal of a battery (through a series resistor and an ammeter) and the n-side to the negative terminal. A voltmeter is connected in parallel with the diode.
• Reverse Bias: Connect the n-side of the diode to the positive terminal of a battery and the p-side to the negative terminal.
• V-I Characteristics: For a silicon diode, the forward current remains negligible until the voltage reaches the threshold/cut-in voltage (approx. 0.7 V). After this, the current increases exponentially. In reverse bias, a very small reverse saturation current (in μA) flows, which remains nearly constant until the breakdown voltage is reached.
(ii) Terminology
(1) Minority Carrier Injection in Forward Biasing: When a p-n junction is forwardbiased, electrons from the n-side cross the junction and enter the p-side, while holes from the p-side enter the n-side. These injected charge carriers become minority carriers in their new regions, significantly increasing minority carrier concentration and causing a sharp rise in current.
(2) Breakdown Voltage in Reverse Biasing: It is the critical reverse bias voltage at which the reverse current increases sharply. At this voltage, the electric field becomes strong enough to break covalent bonds, generating a massive number of electron-hole pairs and causing avalanche or Zener breakdown.

OR

(B) • Two Important Processes: (1) Diffusion of majority charge carriers (holes from p to n, electrons from n to p) and (2) Drift of minority charge carriers driven by the electric field in the depletion region.
• Characteristic Property: A junction diode allows electric current to flow almost entirely in only one direction (when forward-biased) and blocks current flow in the opposite direction (when reverse-biased). This unidirectional property is perfect for rectification (converting alternating current to direct current).

173. **(A) (i)** Magnification Derivation for Near Point

Total magnification M is the product of the magnification of the objective lens (m_o) and the eyepiece (m_e):
$M = m_o \times m_e$
Since $m_o = \frac{v_o}{u_o}$ and the eyepiece acts as a simple microscope with $m_e = \left(1 + \frac{D}{f_e}\right)$, the total magnification formula is:
$$M = \frac{v_o}{u_o}\left(1 + \frac{D}{f_e}\right)$$
(ii) Given:
• Object distance for objective, $u_o = -1.5$ cm
• Focal length of objective, $f_o = 1.25$ cm
• Focal length of eyepiece, $f_e = 5$ cm
• Least distance of distinct vision, $D = 25$ cm (standard near point)
(1) Find v_o using the lens formula for the objective:
$$\frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{f_o}$$
$$\frac{1}{v_o} - \frac{1}{-1.5} = \frac{1}{1.25}$$
$$\frac{1}{v_o} + \frac{2}{3} = \frac{4}{5}$$
$$\frac{1}{v_o} = \frac{4}{5} - \frac{2}{3} = \frac{12 - 10}{15} = \frac{2}{15}$$
$v_o = 7.5$ cm
(2) Calculate Magnifying Power (M):
$$M = \frac{v_o}{|u_o|}\left(1 + \frac{D}{f_e}\right)$$
$$M = \frac{7.5}{1.5}\left(1 + \frac{25}{5}\right)$$
$M = 5 \times (1 + 5) = 5 \times 6 = 30$
The magnifying power of the microscope is 30.

OR

(B) (i) Magnifying Power Derivation
In normal adjustment, the final image is formed at infinity. The magnifying power (M) is the ratio of the angle subtended by the image at the eye (β) to the angle subtended by the distant object at the unaided eye (α).
$$M = \frac{\beta}{\alpha} \approx \frac{\tan\beta}{\tan\alpha}$$
From the ray diagram geometry: $\tan\beta = \frac{h}{f_e}$ and $\tan\alpha = \frac{h}{f_o}$
$$M = \frac{h \div f_e}{h \div f_o} = \frac{f_o}{f_e}$$
(ii) Given:
• Magnifying power, $M = \frac{f_o}{f_c} = 2.9$
• Distance between lenses, $L = f_o + f_e = 150$ cm
(1) Formulate simultaneous equations:
$f_o = 2.9 \times f_e$
Substitute into the length equation:
$2.9f_e + f_e = 150$ cm
$3.9f_e = 150$ cm
(2) Solve for f_e and f_o :
$$f_e = \frac{150}{3.9} = \frac{1500}{39} \approx 38.46 \text{ cm}$$
$f_o = 150 - 38.46 = 111.54$ cm
The focal length of the objective is 111.54 cm and the eyepiece is 38.46 cm.

174. **(i)** Image Formation by Composite Lens
• No, the lens will not produce just one image.

• Explanation: The lens is made of two different materials with refractive indices n_1 and n_2. Since focal length depends on the refractive index ($\frac{1}{f} \propto \mu - 1$), the upper and lower halves will have different focal lengths. As a result, two separate images will be formed along the principal axis.

(ii) Removal of the Screen

• Yes, the real image will still be formed in space at the same location.

• Explanation: A screen does not create the image; it only reflects and scatters the converging light rays so our eyes can see it from different angles. Without the screen, the light rays will still intersect at that specific point in space and then diverge onward.

(iii) Calculation of Radius of Curvature

Given:

• Refractive index, $\mu = 1.55$

• Focal length, $f = +20$ cm

• For a double convex lens, $R_1 = +R$ and $R_2 = -R$

Using Lens Maker's Formula:

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
$$\frac{1}{20} = (1.55 - 1)\left(\frac{1}{R} - \frac{1}{-R}\right)$$
$$\frac{1}{20} = 0.55\left(\frac{2}{R}\right)$$
$$\frac{1}{20} = \frac{1.1}{R}$$
$$R = 20 \times 1.1 = 22 \text{ cm}$$

The required radius of curvature for both faces is 22 cm .

OR

(iii) Step 1: Find the image position for LensA(v_A)

• Focal length, $f_A = +15$ cm

• Object distance, $u_A = -30$ cm

Using the Lens Formula:

$$\frac{1}{v_A} - \frac{1}{u_A} = \frac{1}{f_A}$$
$$\frac{1}{v_A} - \frac{1}{-30} = \frac{1}{15} \Rightarrow \frac{1}{v_A} = \frac{1}{15} - \frac{1}{30} = \frac{1}{30}$$
$$v_A = +30 \text{ cm}$$

Lens A forms a real image 30 cm to its right.

Step 2: Determine the separation distance (d)

• For emerging rays from Lens B to be parallel to the principal axis, the final image must be at infinity ($v_B = \infty$).

• This requires the object for Lens B to be located exactly at its focus ($u_B = -f_B$ =-1cm).

• Therefore, the image formed by Lens A must lie 10 cm to the left of Lens B.

$$d = v_A + |u_B| = 30 \text{ cm} + 10 \text{ cm} = 40 \text{ cm}$$

The distance ' d ' between the two lenses must be 40 cm.

175. **(i)** Equivalent Capacitance Between A and B

By identifying the electrical nodes, this circuit can be redrawn as a classic balanced Wheatstone bridge:

• The four outer arms each contain a capacitor of value C.

• The central vertical arm (the middle capacitor) is connected between two points of equal electrical potential because the bridge is symmetric ($\frac{C}{C} = \frac{C}{C} = 1$).

Since no charge flows through the central capacitor, it can be removed from the calculation. This leaves two parallel branches, each consisting of two capacitors of value C connected in series:

Capacitance of upper branch: $C_{\text{upper}} = \frac{C \times C}{C + C} = \frac{C}{2}$

Capacitance of lower branch: $C_{\text{kwarr}} = \frac{C \times C}{C + C} = \frac{C}{2}$

Combining these two parallel branches gives the total equivalent capacitance:

$$C_{\text{eq}} = C_{\text{upper}} + C_{\text{lowcr}} = \frac{C}{2} + \frac{C}{2} = \text{C}$$

(ii) Reduction of Electric Field by a Dielectric

When a dielectric slab is placed inside an electric field, its molecules undergo polarization. This produces induced surface charges on the opposite faces of the slab, which generate an internal electric field ($\vec{E}_p$) pointing opposite to the external field ($\vec{E}_0$).

The net electric field ($\vec{E}$) inside the dielectric is reduced to:

$$E = E_0 - E_p = \frac{E_0}{K}$$

Since the dielectric constant $K > 1$, the electric field between the plates decreases.

(iii) Capacitor Sharing Problem

Given:

• Capacitor A: $C_A = C$, initial charge $Q_A = Q$

• Capacitor B: $C_B = 2C$, initial charge $Q_B = 0$

(a) Potential difference across the combination

When connected in parallel, the total charge remains conserved ($Q_{\text{total}} = Q$) and the total parallel capacitance is $C_{\text{total}} = C + 2C = 3C$. The common potential difference V is:

$$V = \frac{Q_{\text{total}}}{C_{\text{totall}}} = \frac{\mathrm{Q}}{3\mathrm{C}}$$

(b) Charge lost by capacitor A

The final charge remaining on capacitor A is:

$$Q_A' = C_A \times V = C \times \left(\frac{Q}{3C}\right) = \frac{Q}{3}$$

The charge lost by capacitor A is the difference between its initial and final charge:

$$\Delta Q_A = Q - \frac{Q}{3} = \frac{2Q}{3}$$

OR

(iii) The system behaves as two distinct capacitors connected in series, where each slab spans the entire plate area A :

(1) For the first dielectric slab (2K):

$$C_1 = \frac{(2K)\varepsilon_0 A}{d/3} = \frac{6K\varepsilon_0 A}{d}$$

(2) For the second dielectric slab (K):

$$C_2 = \frac{K\varepsilon_0 A}{2d/3} = \frac{3K\varepsilon_0 A}{2d}$$

Using the series equivalent capacitance formula:

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d}{6K\varepsilon_0 A} + \frac{2d}{3K\varepsilon_0 A}$$

$$\frac{1}{C_{\text{eq}}} = \frac{d + 4d}{6K\varepsilon_0 A} = \frac{5d}{6K\varepsilon_0 A}$$

$$C_{\text{eq}} = \frac{6\ \mathrm{K}\varepsilon_0\ \mathrm{A}}{5\ \mathrm{d}}$$

176. **(d)** Charge on body:

$Q = 8 \times 10^{-12}\mathrm{C}$

Charge of one electron:

$e = 1.6 \times 10^{-19}\mathrm{C}$

Number of electrons:

$$n = \frac{Q}{e} = \frac{8 \times 10^{-12}}{1.6 \times 10^{-19}} = 5 \times 10^7$$

Positive charge means electrons are lost.

177. **(b)** Drift velocity:

$$v_d = \frac{I}{neA}$$

Since current is same and area $A \propto r^2$,

$$v_d \propto \frac{1}{r^2}$$

Given radii ratio:

1: 2
Therefore,
$v_{d1}:v_{d2} = 2^2:1^2 = 4:1$

178. **(b)** Magnetic force:
$F = q(\vec{v} \times \vec{B})$
Since particle is at rest, $v = 0$, so magnetic force is zero.

179. **(c)** Magnetic flux:
$\phi = 3t^2 + 4t + 7$
Induced emf:
$e = \left|\frac{d\phi}{dt}\right|$
$e = 6t + 4$
At $t = 2s$:
$e_2 = 6(2) + 4 = 16$
At $t = 1s$:
$e_1 = 6(1) + 4 = 10$
Ratio:
$\frac{e_2}{e_1} = \frac{16}{10} = 1.6$

180. **(d)** Torque on a current loop:
$\tau = nBIA\sin\theta$
It depends on magnetic field, current and area, but not on shape.

181. **(a)** Magnetic fields due to both coils are equal and perpendicular.
Resultant field:
$B_r = \sqrt{B^2 + B^2} = \sqrt{2}B$
Required ratio:
$\frac{B}{B_r} = \frac{B}{\sqrt{2}B} = \frac{1}{\sqrt{2}}$

182. **(d)** Current due to revolving electron:
I= $\frac{e}{T}$
T = $\frac{2\pi r}{v}$
I = $\frac{ev}{2\pi r}$
Magnetic moment:
$\mu = IA$
$\mu = \frac{ev}{2\pi r} \times \pi r^2 = \frac{evr}{2}$

183. **(c)** Self-inductance increases when iron core is inserted.

184. **(c)** For electromagnetic waves:
$E_0 = cB_0$
$= (3 \times 10^8)(2.4 \times 10^{-8})$
$= 7.2\text{Vm}^{-1}$

185. **(a)** Radius of curvature:
$R = 15$ cm
$f = \frac{R}{2} = 7.5$ cm
Using mirror formula:
$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$
For concave mirror:
$u = -10$ cm, $f = -7.5$ cm
$\frac{1}{v} = \frac{1}{7.5} - \frac{1}{-10}$

$$\frac{1}{v}=-\frac{2}{15}+\frac{1}{10}=\frac{4+3}{30}=-\frac{1}{30}$$
$v=-30$ cm
Negative v means image is real and formed in front of mirror.

186. **(d)** • Reasoning: Using the formula $E=\frac{hc}{\lambda}$, where $h\approx 6.6\times 10^{-34}$ J · s and $c=3\times 10^{8}\text{m/s}$.
• $E=\frac{6.6\times10^{-34}\times3\times10^{8}}{6.6\times10^{-7}}=3.0\times 10^{-19}$ J.

187. **(a)** • Reasoning: Energy of a photon is $E=E_5-E_3$.
• $E_5=\frac{-13.6}{5^2}=-0.544\text{eV}$ and $E_3=\frac{-13.6}{3^2}=-1.511\text{eV}$.
• $E=-0.544-(-1.511)=+0.967\text{eV}\approx+0.97\text{eV}$.

188. **(b)**• Reasoning: Number of neutrons (N) = Mass number (A) - Atomic number (Z).
• $N=237-91=146$.

189. **(c)** Reasoning: Germanium (Ge) and Silicon (Si) are elemental semiconductors, and Cadmium Sulfide (CdS) is a compound semiconductor. Tin (Sn) is a metal.

190. **(c)** Reasoning: In an intrinsic (pure) semiconductor, the number of free electrons is always equal to the number of holes, and both are equal to the intrinsic carrier concentration.

191. **(a)** Assertion (A): True
Reason (R): True
$v=\frac{c}{\mu}$
For a denser medium, $\mu>1$, hence speed decreases.
Reason correctly explains the assertion.
So, Both A and R are true and R is the correct explanation of A.

192. Assertion (A): True
Reason (R): True
Silicon has lower leakage current and can work at higher temperatures than Germanium.
Reason correctly explains the assertion.
So, Both A and R are true and R is the correct explanation of A.

193. **(d)** • Assertion (A) is false: The correct relation between energy (E) and momentum (P) of a photon is $p=\frac{E}{c}$ (where c is the speed of light), not $p=\frac{h}{E}$ (which is dimensionally incorrect).
• Reason (R) is false: While a photon exhibits a dual nature (both wave-like and particle-like), the reason a photon carries momentum is explicitly because it behaves as a particle (a quantum of light). Saying it behaves "as a wave" is not the correct explanation for its momentum.

194. EMF and Internal Resistance
Using the relation $V=E-Ir$:
(1) For $I_1=1.0$ A and $V_1=19$ V :
$19=E-1.0r-(\text{Eq. }1)$
(2) For $I_2=3.0$ A and $V_2=17$ V :
$17=E-3.0r-(\text{Eq. }2)$
Subtracting Eq. 2 from Eq. 1:
$(19-17)=(E-r)-(E-3r)$
$2=2r\Longrightarrow \text{r}=1\Omega$
Substitute $\boldsymbol{r}$ into Eq. 1:
$19=E-I(1)\Longrightarrow E=20$ V

195. **(A)** Displacement Current
Definition: Displacement current is the current that arises in a region where the electric flux (and thus the electric field) is changing with time. It was proposed by Maxwell to make Ampere's law consistent for non-steady currents.
Formula: $I_d=\epsilon_0\frac{d\Phi_E}{dt}$
Example: The current existing in the gap between the plates of a capacitor during its charging or discharging process, where no actual charge carriers flow across the gap. e

OR

(B) Infrared Waves
Wavelength Range: Approximately 700 nm to 1 mm .
Why 'Heat Waves'? Infrared waves are often called heat waves because they are readily absorbed by water molecules and other atoms in most materials. This absorption increases the internal energy and random motion of the molecules, which results in a rise in temperature (heating).

196. Refractive Index and Speed of Light

Refractive Index (n):

$$n=\frac{\text{Real Depth}}{\text{Apparent Depth}}=\frac{9.6\text{ cm}}{7.2\text{ cm}}=\frac{4}{3}\approx 1.33$$

Speed of Light in Water (v):

Using $v=\frac{c}{n}$, where $c=3\times 10^{8}\text{ m/s}$:

$$v=\frac{3\times 10^{8}}{4/3}=\frac{9}{4}\times 10^{8}=2.25\times 10^{8}\text{ m/s}$$

197. Convex lens immersed in a medium

Lens power depends on relative refractive index:

$$P=\left(\frac{n_1}{n_2}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

(A) $n_2>n_1$

$$\frac{n_1}{n_2}<1$$

Hence power becomes negative.
So, the convex lens behaves like a concave lens.

(B) $n_2=n_1$

$$\frac{n_1}{n_2}=1$$

Therefore power becomes zero.
So, the lens loses its converging property and behaves like a plane glass plate.

198. Bohr's postulates of hydrogen atom

(1) Electrons revolve around the nucleus only in certain stable circular orbits without radiating energy.
(2) The angular momentum of the electron is quantized:

$$mvr=\frac{nh}{2\pi}$$

where $n=1,2,3,\ldots$
(3) Radiation is emitted or absorbed only when an electron jumps from one orbit to another.
Photon emission:
When an excited electron jumps from higher energy level E_2 to lower energy level E_1, a photon is emitted with energy:

$$h\nu=E_2-E_1$$

199. Terms related to p-n junction diode

(i) Knee voltage
The minimum forward bias voltage at which diode current starts increasing rapidly is called knee voltage.
(ii) Reverse saturation current
The small current flowing through a reverse-biased diode due to minority charge carriers is called reverse saturation current

200. **(A).** Effect of biasing on depletion region

(i) Forward bias
- Potential barrier decreases.
- Width of depletion region decreases.

(ii) Reverse bias
- Potential barrier increases.
- Width of depletion region increases.

OR

(B). Doping of semiconductor
Doping is the process of adding a small amount of suitable impurity to a pure semiconductor to increase its conductivity.

Necessity:
Pure semiconductors have low conductivity. Doping increases the number of free charge carriers, making the semiconductor useful for electronic devices.

201. Electrical Conductivity and Current Density

The electrical conductivity (σ) of a material represents its ability to allow the flow of electric current.
Factors affecting electrical conductivity:
• Nature of the material: Depends on the density of free charge carriers (n) and the structure of the material.
• Temperature: In conductors, conductivity decreases as temperature increases due to more frequent collisions of charge carriers.
• Relaxation time (τ): The average time between successive collisions of charge carriers.
• Relation between current density (J) and conductivity (σ):
(1) From Ohm's Law, $V = IR$.
(2) Substitute $R = \rho \frac{I}{A}$, where ρ is resistivity, I is length, and A is cross-sectional area:
$V = I\left(\rho \frac{I}{A}\right)$.
(3) Rearrange to find current density $J = \frac{I}{A}$: $V = (JA)\rho \frac{I}{A} \Rightarrow V = J\rho I$.
(4) Since electric field $E = \frac{V}{I}$, we have $E = J\rho$.
(5) Using conductivity $\sigma = \frac{1}{\rho}$, the relation becomes:
$J = \sigma E$
This is the differential form of Ohm's Law.

202. **(A)** LCR Circuit: Resistance, Reactance, and Components

(i) Difference between Resistance and Reactance

Feature d	Resistance (R)	Reactance (X)
Origin	Produced by resistors.	Produced by inductors (X_L) or capacitors (X_C).
Frequency	Independent of frequency.	Depends on the frequency of the AC source.
Phase	Voltage and current are in phase.	There is a phase difference of $\pm\pi/2$.
Energy	Dissipates energy as heat.	Does not dissipate power; energy is stored in fields.

(ii) Blocking DC and Opposing AC
• Capacitor blocks DC: The capacitive reactance is $X_C = \frac{1}{2\pi f C}$. For direct current (DC), frequency $f = 0$, so $X_C \rightarrow \infty$. This infinite resistance blocks DC flow.
• Inductor opposes AC : The inductive reactance is $X_L = 2\pi f L$. For AC , the changing current induces a back EMF (Lenz's Law) that opposes the flow. Higher frequencies result in higher opposition (X_L).

OR

(B) Mathematical Proof: Current Lags Voltage in a Pure Inductor &
(1) Assume an AC voltage: $v = V_m \sin(\omega t)$.
(2) Apply Kirchhoff's Loop Rule: For a pure inductor,

$v-L\frac{di}{dt}=0 \Longrightarrow V_{mr}\sin(\omega t)=L\frac{di}{dt}$

(3) Integrate to find current: $di=\frac{V_m}{L}\sin(\omega t)dt$.

$\int di=\frac{V_m}{L}\int \sin(\omega t)dt \Longrightarrow i=-\frac{V_m}{\omega L}\cos(\omega t)$

(4) Rewrite using Sine: Use the identity $-\cos(\theta)=\sin(\theta-\pi/2)$.

$i=\frac{V_m}{\omega L}\sin\left(\omega t-\frac{\pi}{2}\right)$

(5) Conclusion: Let $I_m=\frac{V_m}{\omega L}$. Then $i=I_m\sin(\omega t-\pi/2)$. Comparing this with v, the current lags the voltage by a phase of $\pi/2$.

203. Self-Inductance

Definition: Self-inductance (L) is the property of a coil by which it opposes any change in the current flowing through it by inducing an EMF in itself.

Expression for a Long Solenoid:

(1) Magnetic Field (B): Inside a long solenoid of N turns and length I.

$B=\mu_0 nI=\mu_0\frac{N}{l}I$

(2) Magnetic Flux (ϕ): Flux through one turn is $\phi_1=BA=\left(\frac{\mu_0 NI}{I}\right)A$.

(3) Total Flux Linkage: For N turns, $\Phi_{\text{total}}=N\phi_1=\frac{\mu_0 N^2 IA}{I}$.

(4) Self-Inductance (L) : Defined as $L=\frac{\Phi_{\text{teral}}}{I}$.

$L=\frac{\mu_0 N^2 A}{l}$

Where μ_0 is the permeability of free space.

204. Einstein's Photoelectric Equation

Einstein's equation is $K_{\max}=hv-\phi_0$ where $\boldsymbol{hv}$ is the energy of the incident photon and ϕ_0 is the work function. It accounts for observations as follows:

(1) Threshold Frequency: If $hv<\phi_0$ the kinetic energy would be negative, which is impossible. Thus, no emission occurs below a specific frequency ($\boldsymbol{v_0}$), regardless of intensity.

(2) Intensity vs. Current: Increasing intensity means more photons per second, leading to more photoelectrons (higher current) if $v>v_0$.

(3) Maximum Kinetic Energy: $K_{\max}$ depends linearly on the frequency ($\boldsymbol{v}$) and is independent of intensity.

(4) Instantaneous Emission: The collision between a photon and an electron is elastic and instantaneous, explaining the lack of time lag.

205. **(A)** Binding energy per nucleon curve

Main features

(1) The binding energy per nucleon increases rapidly for light nuclei and becomes maximum near mass number $A\approx 56$ (iron).

(2) For nuclei heavier than iron, the binding energy per nucleon decreases slowly with increase in mass number.

Conclusions

(1) Nuclei around iron are the most stable.

(2) Energy can be obtained by:

• fusion of light nuclei

• fission of heavy nuclei

OR

(B) Geiger-Marsden experiment

Observations

(1) Most α-particles passed through the gold foil undeflected.

(2) Some particles were deflected through small angles.

(3) Very few particles were deflected through large angles or rebounded.

Conclusions

(1) Most of the atom is empty space.

(2) Positive charge and almost all the mass are concentrated in a very small central nucleus.

(3) The nucleus is dense and positively charged.

206. **(A) (i)** Electric dipole and torque

An electric dipole consists of two equal and opposite charges separated by a small distance.

Dipole moment:

$p = qd$

When placed in a uniform electric field, torque acting on it is:

$\tau = pE\sin\theta$

where θ is the angle between $\vec{p}$ and $\vec{E}$.

(ii) Numerical

Given:

$p = 6 \times 10^{-9}\text{Cm}$

$E = 4 \times 10^{4}\text{NC}^{-1}$

$\theta = 30^\circ$

Torque:

$\tau = pE\sin\theta$

$= (6 \times 10^{-9})(4 \times 10^{4}) \times \frac{1}{2}$

$= 12 \times 10^{-5}$

$= 1.2 \times 10^{-4}$ N m

Torque $= 1.2 \times 10^{-4}\text{Nm}$

OR

(B)(i) Gauss's law

Gauss's law states:

"The total electric flux through a closed surface is equal to $1/\varepsilon_0$ times the total charge enclosed."

$\Phi = \oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$

Electric field due to uniformly charged spherical shell

(1) Outside the shell ($r > R$)

Using Gaussian surface of radius r :

$E(4\pi r^2) = \frac{q}{\varepsilon_0}$

$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$

Thus outside, shell behaves like a point charge.

(2) Inside the shell ($r < R$)

Charge enclosed inside Gaussian surface:

$q_{in} = 0$

Hence,

$E = 0$

Thus electric field inside a charged spherical shell is zero.

(ii) Electric flux through one face of cube

Given:

$q = 4\mu C = 4 \times 10^{-6}C$

Total flux through cube:

$\Phi = \frac{q}{\varepsilon_0}$

Flux through one face:

$\Phi_1 = \frac{q}{6\varepsilon_0}$

$= \frac{4 \times 10^{-6}}{6 \times 8.85 \times 10^{-12}}$

$\approx 7.5 \times 10^{4}$ N m^2/C

Flux through one face $= 7.5 \times 10^{4}$ N m^2/C

207. **(A) (i)** Force between two parallel current-carrying conductors

Magnetic field produced by conductor carrying current I_1 at distance r :

$B = \frac{\mu_0 I_1}{2\pi r}$

Force on length l of second conductor carrying current I_2 :
$F = BI_2 l$
Substituting B :
$$F = \frac{\mu_0 I_1}{2\pi r} I_2 l$$
Therefore force per unit length:
$$\frac{F}{l} = \frac{\mu_0 I_1 I_2}{2\pi r}$$
Definition of one ampere
One ampere is the current which, when maintained in each of two infinitely long parallel conductors placed 1 m apart in vacuum, produces a force of:
$2 \times 10^{-7}\ \mathrm{N/m}$
between them.
Condition for attractive force
The force between conductors is attractive when currents flow in the same direction.
(ii) Magnetic field at centre of circular coil
Given:
$R = 6.28\ \mathrm{cm} = 0.0628\ \mathrm{m}$
$N = 50$
$I = 4\ \mathrm{A}$
Magnetic field at centre:
$$B = \frac{\mu_0 N I}{2R}$$
$$B = \frac{(4\pi \times 10^{-7})(50)(4)}{2(0.0628)}$$
$B = 2 \times 10^{-4}\ \mathrm{T}$
Effect of halving radius
Since:
$$B \propto \frac{1}{R}$$
If radius is halved, magnetic field becomes double.

OR

(B) (i) Helical path in magnetic field
Velocity has two components:
- $v\cos\theta$ along magnetic field
- $v\sin\theta$ perpendicular to magnetic field

The parallel component remains unchanged, while perpendicular component produces circular motion.
Hence resultant path is a helix.
Radius of helix:
$$r = \frac{mv\sin\theta}{qB}$$
(ii) Magnetic field due to straight wire
Given:
$I = 4\ \mathrm{A}$
$r = 20\ \mathrm{cm} = 0.2\ \mathrm{m}$
Magnetic field:
$$B = \frac{\mu_0 I}{2\pi r}$$
$$B = \frac{4\pi \times 10^{-7} \times 4}{2\pi \times 0.2}$$
$B = 4 \times 10^{-6}\ \mathrm{T}$
Direction
Using right-hand thumb rule:
- Thumb towards east (direction of current)
- At a point below the wire, magnetic field is towards south.

Magnitude $= 4 \times 10^{-6}$ T
Direction = South

208. **(A) (i)** Total internal reflection

Total internal reflection is the phenomenon in which a ray of light travelling from a denser medium to a rarer medium gets completely reflected back into the denser medium.

Conditions required
(1) Light must travel from denser medium to rarer medium.
(2) Angle of incidence in denser medium must be greater than the critical angle.

Technological application
Optical fibre communication
Optical fibres work on total internal reflection. Light signals undergo repeated total internal reflections inside the fibre and travel long distances with very small loss of energy.

(ii) Combination of lenses
Given:
$f_1 = +10$ cm
$f_2 = -15$ cm
For lenses in contact:
$$\frac{1}{p} = \frac{1}{f_1} + \frac{1}{f_2}$$
$$\frac{1}{F} = \frac{1}{10} - \frac{1}{15}$$
$$= \frac{3-2}{30} = \frac{1}{30}$$
$F = 30$ cm
Since focal length is positive, the combination behaves as a converging lens.
Nature: Converging
Focal length $= 30$ cm

OR

(B) (i) Reasons
(1) Simple microscope gives magnification
Although angular size of image equals angular size of object, the image is formed closer to the eye than the object seen directly. Hence the object subtends a larger angle at the eye and appears magnified.
(2) Short focal lengths in compound microscope
Both objective and eyepiece have short focal lengths to obtain large magnification.
(3) Difference between microscope and telescope
• Microscope is used for observing tiny nearby objects; high magnification and high resolution are important.
• Telescope is used for distant objects; collecting more light and improving angular resolution are important.

(ii) Fringe width in YDSE
Given:
$d = 1.0$ mm $= 10^{-3}$ m
$\lambda = 600$ mm $= 6 \times 10^{-7}$ m
$D = 2.0$ m
Fringe width:
$$\beta = \frac{\lambda D}{d}$$
$$\beta = \frac{(6 \times 10^{-7})(2)}{10^{-3}}$$
$= 1.2 \times 10^{-3}$ m
$= 1.2$ mm
Fringe width $= 1.2$ mm

209. **(i)** Sphere Transferring Electrons
• Sphere S_1 will transfer electrons to Sphere S_2.
• Electrons are negatively charged particles.
• They naturally flow from a region of excess negative charge (lower potential, S_1) to a region of deficit negative charge (higher potential, S_2).

(ii) Change in Net Electric Field

• The net electric field drops to zero.
• Before contact: The fields from the negative sphere S_1 and positive sphere S_2 both point in the same direction at the midpoint, adding up to a large value.
• After contact: Both identical spheres acquire the exact same negative charge $(-3q)$. Their electric fields at the midpoint point in opposite directions and completely cancel out.
(iii) Initial Charge on Spheres S_1 and S_2
Using Coulomb's Law for the initial setup:
$$F=\frac{1}{4\pi\varepsilon_0}\cdot\frac{|q_1\cdot q_2|}{r^2}$$
Substitute the given values ($F=8.1\times10^{-4}$ N, $r=1.6$ m):
$$8.1\times10^{-4}=(9\times10^9)\cdot\frac{|(-8q)\cdot(2q)|}{(1.6)^2}$$
$$8.1\times10^{-4}=\frac{9\times10^9\cdot16q^2}{2.56}$$
$$q^2=\frac{8.1\times10^{-4}\cdot2.56}{1.44\times10^{11}}=1.44\times10^{-14}$$
$q=1.2\times10^{-7}\mathrm{C}$
Now, compute the initial charges:
• Initial charge on S_1 : $-8q=-8\times(1.2\times10^{-7})=-9.6\times10^{-7}\mathrm{C}$
• Initial charge on S_2: $+2q=+2\times(1.2\times10^{-7})=+2.4\times10^{-7}\mathrm{C}$

OR

(iii) Charge on Spheres After Contact
When identical spheres touch, total charge redistributes equally:
$$q_{\text{final}}=\frac{q_1+q_2}{2}=\frac{-8q+2q}{2}=-3q$$
Using the value of $q=1.2\times10^{-7}\mathrm{C}$ calculated above:
• Final charge on S_1: $-3\times(1.2\times10^{-7})=-3.6\times10^{-7}\mathrm{C}$
• Final charge on S_2: $-3\times(1.2\times10^{-7})=-3.6\times10^{-7}\mathrm{C}$

210. The most essential condition for observing diffraction is that the size of the obstacle or aperture must be comparable to the wavelength of the incident light. If the obstacle is significantly larger than the wavelength, light casts a sharp shadow and rectilinear propagation dominates.
(i) What is the most essential condition for observing diffraction?
The size of the aperture or obstacle must be on the same order of magnitude as the wavelength of the incident light wave.
(ii) Which characteristic of light is used in X-ray crystallography?
The wave nature of light (specifically, X-ray diffraction) is used. Because the atomic spacing in crystal lattices perfectly matches the short wavelengths of X-rays ($\sim$ 1Å), the crystals act as natural 3D diffraction gratings.
(iii) How does the wave theory of light provide an explanation for diffraction? Explain.
According to the wave theory (based on the Huygens-Fresnel principle), when a wavefront passes through an aperture or around an obstacle, every unobstructed point on the wavefront acts as a source of secondary wavelets. These secondary wavelets spread out in all directions, overlapping and interfering with each other. This mutual interference causes light to bend into the geometrical shadow, producing a diffraction pattern of varying intensities.

OR

(iii) In a single slit diffraction, if red light is replaced by blue light, then how does the diffraction pattern change?
Replacing red light with blue light decreases the wavelength of the incident light (red is $\sim$ 700 nm, blue is $\sim$ 450 nm). Since fringe width β is directly proportional to the wavelength ($\beta=\frac{\lambda D}{d}$), the following changes occur:
• Fringe width decreases: The diffraction fringes (and the central maximum) become narrower.
• Fringes get closer: The fringes are crowded more closely together toward the center.