1. **(d)** • Potential energy of the system

For three charges at the vertices of an equilateral triangle of side l,

$$U=\frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{l}+\frac{q_2q_3}{l}+\frac{q_3q_1}{l}\right)$$

Here,

$q_1=2q, q_2=-2q, q_3=q$

$$U=\frac{1}{4\pi\varepsilon_0 l}[(2q)(-2q)+(-2q)(q)+(q)(2q)]$$

$$U=\frac{1}{4\pi\varepsilon_0 l}(-4q^2-2q^2+2q^2)$$

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

$$U=\frac{q^2}{\pi\varepsilon_0 l}$$

2. **(d)** • Two spheres brought into contact

When two conducting spheres are connected:

• Total charge is conserved

• Both attain the same potential

Common potential:

$$V=\frac{1}{4\pi\varepsilon_0}\frac{q_1+q_2}{r_1+r_2}$$

Thus (c) is correct.

$$V=\frac{1}{4\pi\varepsilon_0}\frac{(q_1+q_2)(r_1+r_2)}{r_1r_2}$$

is incorrect.

3. **(d)** • Maximum kinetic energy in photoelectric effect

Einstein's equation:

$K_{max}=h\nu-\phi_0$

Thus K_{max} depends on:

• Frequency ν

• Work function ϕ_0

and is independent of intensity.

4. **(b)** Consecutive Bohr orbits

Radius of n^{th} orbit:

$r_n=n^2a_0$

Distance between consecutive orbit:

$r_{n+1}-r_n=a_0[(n+1)^2-n^2]$

$=a_0(2n+1)$

For large n,

$r_{n+1}-r_n\propto n$

5. **(a)** • Direction of magnetic field

Wire lies along y -axis and current flows along - y.

Point:

(50 cm, 0,0)

lies on the +x-axis.

Using the right-hand thumb rule:

• Thumb along - y

• Magnetic field at +x points along +z

6. **(b)** • Material with positive and small magnetic susceptibility

• Cu – Diamagnetic ($\chi<0$)

• Bi → Diamagnetic ($\chi<0$)

• Ni → Ferromagnetic (very large χ)

• AI - Paramagnetic (small positive χ)

7. **(c)** • Galvanometer converted to ammeter

Given:
$G = 27\Omega, S = 3\Omega$
Ammeter range:
$I = 10 \text{ mA}$
For full-scale deflection,
$I_g G = (I - I_g)S$
$27I_g = 3(10 - I_g)$
$9I_g = 10 - I_g$
$10I_g = 10$
$I_g = 1 \text{ mA}$
Thus galvanometer shows full-scale deflection at
= 1 mA

8. **(c)** • Units of A and B
Given:
$\phi = 5At^2 + Bt - 2C$
Magnetic flux ϕ has unit Wb.
Therefore each term must have unit Wb.
For At^2 :
$$[A] = \frac{Wb}{s^2} = Wbs^{-2}$$
For Bt :
$$[B] = \frac{Wb}{s} = Wbs^{-1}$$

9. **(d)** Ratio C_1/C_2
For a capacitor,
$$X_C = \frac{1}{\omega C}$$
Thus graph of X_C versus $\frac{1}{\Delta}$ is a straight line with slope
$$m = \frac{1}{C}$$
Hence
$$\frac{C_1}{C_2} = \frac{m_2}{m_1}$$
From graph:
• Line C_1 makes 45° with x-axis.
• Line C_2 makes 30° with x-axis.
$m_1 = \tan 45^\circ = 1$
$$m_2 = \tan 30^\circ = \frac{1}{\sqrt{3}}$$
Therefore
$$\frac{C_1}{C_2} = \frac{1/\sqrt{3}}{1} = \frac{1}{\sqrt{3}}$$

10. **(a)** • Magnet dropped into a closed solenoid
The north pole of the magnet is moving downward towards the solenoid.
By Lenz's law, the induced current opposes the approach of the north pole. Therefore, the upper end of the solenoid must behave like a north pole.
Using the clock-face rule:
• Anticlockwise current (viewed from the top) ⇒ upper face becomes North.

11. **(a)** • Phase difference between $\vec{E}$ and $\vec{B}$
In an electromagnetic wave,
• Electric field $\vec{E}$ and magnetic field $\vec{B}$ oscillate in phase.
• They attain maxima and minima simultaneously.

Therefore,
$\Delta\phi = 0$

12. (d) • Bohr atom transition

For hydrogen atom,
$$\frac{1}{\lambda} = R\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$
Transition $5 \to 1$
$$\frac{1}{\lambda} = R\left(1 - \frac{1}{25}\right) = R\frac{24}{25}$$
Transition $5 \to 2$

Let wavelength be λ'.
$$\frac{1}{\lambda'} = R\left(\frac{1}{4} - \frac{1}{25}\right) = R\frac{21}{100}$$
Hence,
$$\frac{\lambda'}{\lambda} = \frac{\frac{24}{25}}{\frac{21}{100}} = \frac{24 \times 100}{25 \times 21} = \frac{32}{7}$$
$$\lambda' = \frac{32}{7}\lambda$$

13. (b) • Assertion (A): On increasing the intensity of incident light of frequency $v > v_0$) on a photosensitive surface, the photocurrent increases.

Status: True

• Explanation: Photocurrent is directly proportional to the intensity of the incident light because higher intensity means more photons striking per second, releasing more photoelectrons.

• Reason (R): The stopping potential for a photosensitive surface increases with increase of frequency $v(> v_0)$ of incident light.

Status: True

• Explanation: According to Einstein's photoelectric equation ($eV_0 = h\nu - \phi_0$). stopping potential V_0 increases linearly with frequency v.

• Conclusion: Both statements are correct, but the stopping potential's dependence on frequency does not explain why intensity increases photocurrent.

14. (d) • Assertion (A): On forward biasing a p-n junction diode, the height of the barrier potential increases.

Status: False

• Explanation: In forward bias, the applied external voltage opposes the built-in potential barrier, reducing its height and width.

• Reason (R): In forward biasing of a p-n junction diode, the direction of the applied voltage is in the same direction as the built-in potential.

Status: False

• Explanation: The built-in potential field points from the n -region to the p -region. In forward bias, the applied voltage points from the p-region to the n-region (opposing direction).

15. (a) • Assertion (A): Light added to light can produce darkness.

Status: True

• Explanation: This phenomenon occurs due to the wave nature of light during destructive interference.

• Reason (R): When two coherent light waves interfere, there is darkness at position of destructive interference.

Status: True

• Explanation: When two coherent waves meet out of phase (crest meets trough), they cancel each other out, resulting in zero intensity (darkness).

• Conclusion: The reason is the correct and accurate explanation of the assertion.

16. (c) • Assertion (A): Two electric heaters of power P_1 and $P_2(> P_1)$ are joined in series across a dc source of voltage V. The power consumed by the combination will be less than that consumed by P_1 when connected across the same source.

Status: True

• Explanation: Resistance is given by $R = \frac{V^2}{P}$. In series, total resistance increases ($R_s = R_1 + R_2$). Since $R_s > R_1$, the total power consumed $P_s = \frac{V^2}{R_z}$ will be less than $P_1 = \frac{V^2}{R_1}$.
• Reason (R): The power consumed by an electric device when connected to a dc source of voltage V is proportional to its resistance.
• Status: False
• Explanation: When connected across a constant voltage source V, power is inversely proportional to resistance $\left(P = \frac{V^2}{R}\right)$.

17. Two differences between intrinsic and extrinsic semiconductors

Intrinsic Semiconductor	Extrinsic Semiconductor
Pure semiconductor without impurities.	Semiconductor doped with suitable impurities.
Number of electrons = number of holes (n = p).	Electrons and holes are unequal; one type is the majority carrier.

18. Ratio $\left(\lambda_a/\lambda_p\right)$

(i) Same kinetic energy

De Broglie wavelength:

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

For same kinetic energy K,

$$\lambda \propto \frac{1}{\sqrt{m}}$$

Hence

$$\frac{\lambda_a}{\lambda_p} = \sqrt{\frac{m_p}{m_a}}$$

Since

$$m_a = 4m_p$$

$$\frac{\lambda_a}{\lambda_p} = \sqrt{\frac{1}{4}} = \frac{1}{2}$$

$$\frac{\lambda_a}{\lambda_p} = \frac{1}{2}$$

(ii) Accelerated through the same potential difference

For a particle accelerated through potential V.

$$K = qV$$

and

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

Therefore,

$$\frac{\lambda_a}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_a q_a}}$$

For alpha particle,

$$m_a = 4m_p, q_a = 2e$$

For proton,

$q_p = e$

Thus

$$\frac{\lambda_a}{\lambda_p} = \sqrt{\frac{m_p e}{(4m m_p)(2e)}} = \frac{1}{\sqrt{8}}$$

$$\frac{\lambda_a}{\lambda_p} = \frac{1}{2\sqrt{2}}$$

19. Speed of light in the prism

Given:

• Equilateral prism

$A = 60^\circ$

• At minimum deviation,

$$i = \frac{3}{4}A = \frac{3}{4} \times 60^\circ = 45^\circ$$

For minimum deviation,

$$\mu = \frac{\sin i}{\sin(A/2)}$$

$$\mu = \frac{\sin 45^\circ}{\sin 30^\circ} = \frac{\frac{1}{\sqrt{2}}}{\frac{1}{2}} = \sqrt{2}$$

Speed of light in prism:

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

$$v = \frac{3 \times 10^8}{\sqrt{2}}$$

$v \approx 2.12 \times 10^8 \text{ m s}^{-1}$

20. Steady temperature of nichrome heater

Given:

$V = 220 \text{ V}$

$I_1 = 2.9 \text{ A}(27^\circ\text{C})$

$I_2 = 2.5 \text{ A}$

$\alpha = 1.7 \times 10^{-4} \, ^\circ\text{C}^{-1}$

Initial resistance

$$R_1 = \frac{V}{I_1} = \frac{220}{2.9} = 75.86\Omega$$

Final resistance

$$R_2 = \frac{220}{2.5} = 88\Omega$$

Using

$R_2 = R_1[1 + \alpha(T - 27)]$

$88 = 75.86[1 + 1.7 \times 10^{-4}(T - 27)]$

$$\frac{88}{75.86} = 1 + 1.7 \times 10^{-4}(T - 27)$$

$1.1600 = 1 + 1.7 \times 10^{-4}(T - 27)$

$$T - 27 = \frac{0.1600}{1.7 \times 10^{-4}} \approx 941$$

$T \approx 968^\circ\text{C}$

$T \approx 9.7 \times 10^2 \, ^\circ\text{C}$

or

$T \approx 968^\circ\text{C}$

21. Concave Mirror Problem

Given:

• Focal length of concave mirror, $f = -20$ cm

• Length of the pencil, $L = 5$ cm
• Position of nearest end, $u_1 = -25$ cm
• Position of farther end, $u_2 = -(25+5) = -30$ cm
Using the mirror formula: $\frac{1}{v}+\frac{1}{u}=\frac{1}{f} \Rightarrow \frac{1}{v}=\frac{1}{f}-\frac{1}{u}$
(1) For the nearest end ($u_1 = -25$ cm):
$$\frac{1}{v_1}=\frac{1}{-20}-\frac{1}{-25}=-\frac{1}{20}+\frac{1}{25}=\frac{-5+4}{100}=-\frac{1}{100} \Rightarrow v_1=-100 \text{ cm}$$
(2) For the farther end ($u_2 = -30$ cm):
$$\frac{1}{v_2}=\frac{1}{-20}-\frac{1}{-30}=-\frac{1}{20}+\frac{1}{30}=\frac{-3+2}{60}=-\frac{1}{60} \Rightarrow v_2=-60 \text{ cm}$$
• Length of the image:
Length $=|v_1-v_2|=|-100-(-60)|=40$cm

OR

• Young's Double-Slit Experiment
Given:
• Wavelengths: $\lambda_1 = 500 \text{ nm} = 5\times10^{-7} \text{ m}, \lambda_2 = 600 \text{ nm} = 6\times10^{-7} \text{ m}$
• Screen distance: $D = 1.8$ m
• Slit separation: $d = 0.3 \text{ mm} = 3\times10^{-4}$ m
For the bright fringes to coincide at a distance y from the central maximum:
$$y=\frac{n_1\lambda_1 D}{d}=\frac{n_2\lambda_2 D}{d} \Rightarrow n_1\lambda_1=n_2\lambda_2$$
$$\frac{n_1}{n_2}=\frac{\lambda_2}{\lambda_1}=\frac{600}{500}=\frac{6}{5}$$
The lowest integral values are $n_1 = 6$ and $n_2 = 5$.
• Least distance (y):
$$y=\frac{6\times(500\times10^{-9} \text{ m})\times1.8 \text{ m}}{3\times10^{-4} \text{ m}}=1.8\times10^{-2} \text{ m}=1.8\text{cm}(\text{ or } 18 \text{ mm})$$

22. **(A)** Classification of Nuclides
• Isotopes (Same atomic number Z. different mass number A):
$^{12}_{6}C$ and $^{14}_{6}C$
• Isotones (Same number of neutrons $N = A - Z$):
• For $^{198}_{80}Hg$: $N = 198 - 80 = 118$
• For $^{197}_{79}Au$: $N = 197 - 79 = 118$
$^{198}_{80}Hg$ and $^{197}_{79}Au$
(B) Nuclear Size and Density Proof
• Size dependence: The nuclear radius R is directly proportional to the cube root of its mass number A :
$R = R_0A^{1/3}$ (where $R_0 \approx 1.2\times10^{-15}$ m)
• Density proof:
$$\text{Volume of nucleus, } V=\frac{4}{3}\pi R^3=\frac{4}{3}\pi\left(R_0A^{1/3}\right)^3=\frac{4}{3}\pi R_0^3 A$$
Mass of nucleus, $M = A\times m$ (where m = average mass of a nucleon)
$$\text{Density, } \rho=\frac{\text{Mass}}{\text{Volume}}=\frac{A\cdot m}{\frac{4}{3}\pi R_0^3 A}=\frac{3m}{4\pi R_0^3}$$
Since m and R_0 are constants, density ρ is a constant independent of A.

23. **(A)** Equipotential Surfaces for $\vec{E} = E_0\hat{i}$
• The electric field is uniform and directed along the positive x-axis.
• Equipotential surfaces are always perpendicular to the electric field lines.
• Therefore, the surfaces are parallel planes perpendicular to the x -axis (i.e., parallel to the $y - z$ plane).
(B) Electrostatic Potential of a Dipole
• Charges $-q$ and $+q$ are at $(-a,0,0)$ and $(a,0,0)$. This forms an electric dipole with dipole moment $\vec{p} = (2aq)\hat{i}$.
• Potential at any point x along the axis ($x \gg a$):
$$V=\frac{1}{4\pi\varepsilon_0}\left[\frac{q}{x-a}+\frac{-q}{x+a}\right]=\frac{q}{4\pi\varepsilon_0}\left[\frac{(x+a)-(x-a)}{x^2-a^2}\right]=\frac{2aq}{4\pi\varepsilon_0(x^2-a^2)}$$

• Since $x > 0, x^2 - a^2 \approx x^2$:

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

24.

Application	Electromagnetic Wave	Wavelength Range (Approximate)
(I) Detection of bone fractures	X-rays	10^{-11} m to 10^{-8} m(0.01 nm to 10 nm)
(II) Physiotherapy	Infrared waves	700 nm to 1 mm
(III) Radar systems	Microwaves	1 mm to 1 m

25. **(i)** Mutual Inductance and its SI Unit

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

• Mathematical Relation: The magnetic flux (ϕ_s) linked with the secondary coil is directly proportional to the current (I_p) in the primary coil:

$$\phi_s = MI_p$$

where M is the coefficient of mutual inductance.

• SI Unit: The SI unit of mutual inductance is the Henry (H).

(ii) Mutual Inductance of a Solenoid and a Loop

• Let a steady current I flow through the long solenoid.

• The uniform magnetic field B inside a long solenoid near its center is given by:

$$B = \mu_0 nI$$

• Since the circular loop of radius r is situated inside the center of the solenoid with coinciding axes, the magnetic flux ϕ passing through the loop area $(A = \pi r^2)$ is:

$$\phi = B \cdot A = (\mu_0 nI) \cdot (\pi r^2)$$

• By definition, the flux linked with the loop is related to mutual inductance M by:

$$\phi = MI$$

• Equating the two expressions for flux:

$$MI = \mu_0 nI\pi r^2 \Rightarrow M = \mu_0 n\pi r^2$$

OR

• Force between two long parallel conductors:

• Consider two long parallel wires A and B separated by a distance d, carrying currents I_a and I_b in the same direction.

• The magnetic field B_a produced by conductor A at the location of conductor B is:

$$B_a = \frac{\mu_0 I_a}{2\pi d}$$

• According to the right-hand grip rule, the direction of B_a is perpendicular to the plane containing the wires and points into the page.

• The magnetic force F_{ba} acting on a length L of conductor B due to the magnetic field B_a is:

$$F_{ba} = I_b L B_a = \frac{\mu_0 I_a I_b L}{2\pi d}$$

• Using Fleming's Left-Hand Rule, the direction of this force is directed towards conductor A (attractive force).

• Similarly, the magnetic force F_{ab} acting on a length L of conductor A due to the magnetic field B_b created by conductor B is:

$$F_{ab} = I_a L B_b = I_a L\left(\frac{\mu_0 I_b}{2\pi d}\right) = \frac{\mu_0 I_a I_b L}{2\pi d}$$

• By Fleming's Left-Hand Rule, this force acts towards conductor B.

• Since $\vec{F}_{ab}$ and $\vec{F}_{ba}$ are equal in magnitude and opposite in direction:

$\vec{F}_{ab} = -\vec{F}_{ba}$

• This proves that the mutual forces between the parallel current-carrying conductors satisfy Newton's third law of motion.

26. **(A)** Bohr's Second Postulate and Significance

• Postulate: An electron can revolve only in specific non-radiating, stable orbits where its total orbital angular momentum (L) is an integral multiple of $\frac{h}{2x}$:

$$L = mvr = \frac{nh}{2\pi}$$

where m is the electron mass, v is the orbital velocity, r is the radius of the orbit, h is Planck's constant, and n is the principal quantum number ($n = 1,2,3, \ldots$).

• Significance: It introduces the quantization of angular momentum, which ensures that electrons occupying these discrete orbits do not continuously radiate energy and spiral into the nucleus, thereby explaining atomic stability.

(B) Convergence of Energy Levels for Large n

• The total energy of an electron in the n-th orbit of a hydrogen atom is:

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

• The energy difference ΔE between two consecutive levels n and n + 1 is:

$$\Delta E = E_{n+1} - E_n = -13.6\left[\frac{1}{(n+1)^2} - \frac{1}{n^2}\right] = 13.6\left[\frac{2n+1}{n^2(n+1)^2}\right]$$

• For very large principal quantum numbers ($n > 1$), we approximate $2n + 1 \approx 2n$ and $n + 1 \approx n$.

$$\Delta E \approx 13.6\left(\frac{2n}{n^4}\right) = \frac{27.2}{n^3}$$

• As $n \to \infty$, the energy difference approaches zero ($\Delta E \to 0$), proving that successive energy levels get closer and closer together as n becomes large.

27. **(A)** Scalar Nature of Electric Current

• Electric current is a scalar quantity because it does not obey the laws of vector addition (such as the parallelogram or triangle law).

• When multiple current-carrying wires meet at a junction, the total resulting current is simply the ordinary algebraic sum of the currents, completely independent of the angles between the wires. The arrow simply denotes the directional flow of positive charge carriers.

(B) Circuit Analysis Using Kirchhoff's Rules

• Let I_1 be the current flowing clockwise through the left loop (AFEBA), starting upward from the 3 V battery.

• Let I_2 be the current flowing clockwise through the right loop (BCDEB), leaving the positive terminal of the 5 V battery.

• Applying Kirchhoff's Current Law (KCL) at junction B, the downward current through the middle 3Ω resistor is:

$I_3 = I_1 - I_2$

Applying Kirchhoff's Voltage Law (KVL) to the individual loops:

(1) Left Loop (AFEBA):

$3 - 3(I_1 - I_2) - 4I_1 = 0 \Rightarrow 7I_1 - 3I_2 = 3$ ....(i)

(2) Right Loop (BCDEB):

$-5 - 2I_2 + 3(I_1 - I_2) = 0 \Rightarrow 3I_1 - 5I_2 = 5$ ....(ii)

Solving Equations 1 and 2 simultaneously:

• From Equation 1: $I_2 = \frac{7I_1 - 3}{3}$

• Substitute into Equation 2:

$$3I_1 - 5\left(\frac{7I_1 - 3}{3}\right) = 5$$

$9I_1 - 35I_1 + 15 = 15 \Rightarrow -26I_1 = 0 \Rightarrow I_1 = 0 \text{ A}$

• Substituting $I_1 = 0$ A back into the expression for I_2 :

$$I_2 = \frac{7(0) - 3}{3} = -1 \text{ A}$$

Now, compute the current (I_3) passing through the 3Ω resistor:

$I_3 = I_1 - I_2 = 0 - (-1) = 1 \text{ A}$

28. Magnetic field on the axis of a circular coil

Consider a circular coil of.

• Radius r

• Number of turns N
• Current I
Let P be a point on the axis of the coil at a distance x from its centre O.
Step 1: Magnetic field due to a current element
From the Biot-Savart law,
$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l} \times \hat{r})}{r'^2}$$
where r' is the distance of the current element from point P.
For a circular loop.
$$r' = \sqrt{r^2 + x^2}$$
is the same for all elements.
Step 2: Resolve the magnetic field
Due to symmetry:
• Components of $d\vec{B}$ perpendicular to the axis cancel out.
• Only the axial components add up.
Hence,
$$dB_{axis} = dB\cos\theta$$
where
$$\cos\theta = \frac{r}{\sqrt{r^2 + x^2}}$$
Also,
$$dB = \frac{\mu_0}{4\pi}\frac{Idl}{(r^2 + x^2)}$$
Therefore,
$$dB_{axis} = \frac{\mu_0}{4\pi}\frac{Irdl}{(r^2 + x^2)^{3/2}}$$
Step 3: Integrate over the complete loop
$$B = \frac{\mu_0 Ir}{4\pi(r^2 + x^2)^{3/2}}\oint dl$$
Since
$$\oint dl = 2\pi r$$
$$B = \frac{\mu_0 Ir}{4\pi(r^2 + x^2)^{3/2}}(2\pi r)$$
$$B = \frac{\mu_0 Ir^2}{2(r^2 + x^2)^{3/2}}$$
For a coil of N tums,
$$B = \frac{\mu_0 NIr^2}{2(r^2 + x^2)^{3/2}}$$
The magnetic field is directed along the axis of the coil according to the right-hand thumb rule.
Special case: At the centre of the coil ($x = 0$)
$$B = \frac{\mu_0 NIr^2}{2r^3}$$
$$B = \frac{\mu_0 NI}{2r}$$
This is the magnetic field at the centre of a circular coil.

29. **(i) (c)** Silicon is doped with which impurity to obtain p-type semiconductor?
A p-type semiconductor is obtained by doping silicon with a trivalent impurity.
Among the given options:
• Phosphorus → Pentavalent
• Arsenic - Pentavalent
• Boron - Trivalent
• Antimony - Pentavalent

(ii) (d) • Hole concentration
Given:

$n = 5 \times 10^{22}\ m^{-3}$
$n_i = 1.5 \times 10^{16}\ m^{-3}$
Using
$np = n_i^2$
$p = \frac{n_i^2}{n}$
$p = \frac{(1.5 \times 10^{16})^2}{5 \times 10^{22}}$
$= \frac{2.25 \times 10^{32}}{5 \times 10^{22}}$
$= 4.5 \times 10^9\ m^{-3}$
(iii) (a) • During forward biasing of a p-n junction diode
In forward bias, the barrier potential decreases and the current is mainly due to diffusion of majority carriers across the junction.
(iv) (c) • Threshold voltage for silicon diode
For silicon:
$V_{threshold} \approx 0.7\ V$

OR

(iv) (a) • Ionisation energy of donor electron in Ge doped with a pentavalent impurity
The fifth electron is loosely bound and requires about
0.01eV
to become free.

30. (i) (a)
• Value of d
Using the lens displacement method:
$d = \sqrt{D(D - 4f)}$
(ii) (d)
• Nature of the two images
In the first position (lens near the object):
$v > u$
Image is enlarged.
In the second position (lens near the screen):
$u > v$
Image is reduced.
(iii) (b)
• Find focal length
Given:
$D = 80\ cm, d = 20\ cm$
Using
$f = \frac{D^2 - d^2}{4D}$
$f = \frac{80^2 - 20^2}{4 \times 80}$
$= \frac{6400 - 400}{320}$
$= \frac{6000}{320}$
$= 18.75\ cm$
(iv) (d)
Convex lens of focal length 15 cm
For two sharp images to be obtained,
$D > 4f$
$D > 4(15) = 60\ cm$
Among the options, only
65 cm

satisfies the condition.

OR

(iv) (a)

Combination of lenses

Given:

$f_1 = 10$ cm

Power of combination:

$P = \frac{10}{3} D$

$P = P_1 + P_2$

$\frac{10}{3} = \frac{100}{10} + \frac{100}{f'}$

$\frac{10}{3} = 10 + \frac{100}{f'}$

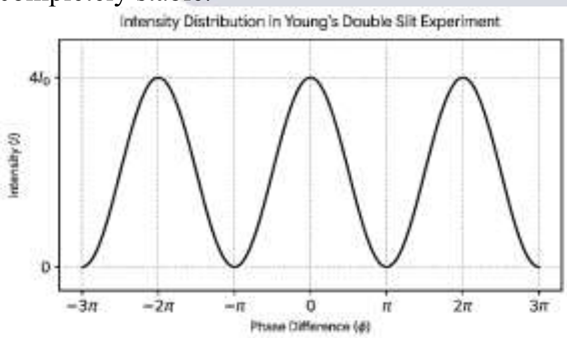
$\frac{100}{f'} = \frac{10}{3} - 10 = -\frac{20}{3}$

$f' = \frac{100 \times 3}{20} = -15$ cm

31. (A) (i) Coherent Sources & YDSE Intensity Graph

• Coherent Sources: Light sources that emit light waves with the same frequency (or wavelength) and a constant or zero phase difference over time.

• Necessity for Stable Interference: Incoherent sources have rapidly and randomly changing phase differences. This causes the bright and dark fringe positions to shift millions of times per second, blurring the pattern into uniform illumination. Coherent sources maintain a fixed phase relationship, keeping the fringe positions completely stable.



(B) Intensity Calculation

The general equation for the resultant intensity of two interfering waves of equal intensity I_0 is:

$I = 4I_0 \cos^2\left(\frac{\phi}{2}\right)$

The relationship between phase difference (ϕ) and path difference (Δx) is:

$\phi = \frac{2\pi}{\lambda} \cdot \Delta x$

(i) For path difference $\Delta x = \frac{1}{4}$:

• Phase difference: $\phi = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4} = \frac{\pi}{2}$

• Resultant intensity:

$I = 4I_0 \cos^2\left(\frac{\pi}{4}\right) = 4I_0 \left(\frac{1}{\sqrt{2}}\right)^2 = 2I_0$

(ii) For path difference $\Delta x = \frac{1}{3}$:

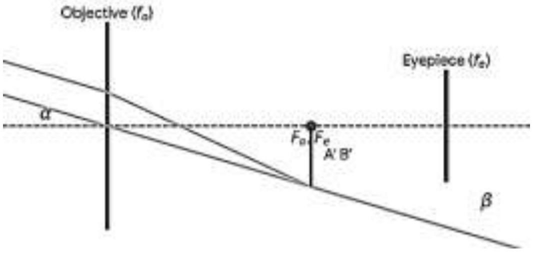
• Phase difference: $\phi = \frac{2x}{\lambda} \cdot \frac{\lambda}{3} = \frac{2x}{3}$

• Resultant intensity:

$I = 4I_0 \cos^2\left(\frac{\pi}{3}\right) = 4I_0 \left(\frac{1}{2}\right)^2 = I_0$

OR

(A) Refracting Telescope in Normal Adjustment



Derivation of Magnifying Power (m):
Magnifying power is the ratio of the angle subtended by the final image at the eye (ff) to the angle subtended by the object at the objective (α).

$$m = \frac{\beta}{\alpha}$$

Since α and β are very small angles:

$$\alpha \approx \tan\alpha = \frac{A'B'}{OB'} = \frac{A'B'}{f_o}$$

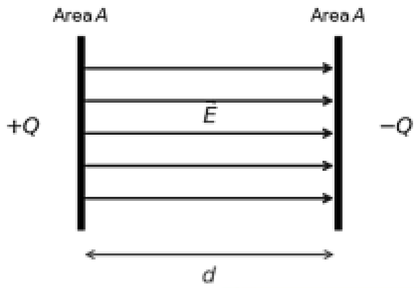
$$\beta \approx \tan\beta = \frac{A'B'}{EB'} = \frac{A'B'}{-f_e}$$

Substituting these values into the magnifying power equation gives:

$$m = \frac{\frac{A'B'}{-f_e}}{\frac{A'B'}{f_o}} = -\frac{f_o}{f_e}$$

(B) Design and Advantages
(i) Purpose of Larger Objective Aperture:
• Light Gathering: Collects more light photons from faint, distant stars to produce bright images.
• Resolving Power: Increases resolution (R.P. $\propto$ D) to distinguish closely spaced celestial bodies clearly.
(ii) Advantages of Reflecting Telescopes:
• No Chromatic Aberration: Mirrors reflect all light wavelengths equally without splitting colors.
• No Spherical Aberration: Parabolic mirrors bring all parallel incoming light rays to a single focal point.

32. **(A)** Derivation of Capacitance of a Parallel Plate Capacitor
Consider a parallel plate capacitor consisting of two parallel conducting plates, each of area A, separated by a small distance d with air/vacuum in between. Let a charge $+Q$ be given to one plate and $-Q$ to the other.



(1) Surface Charge Density (σ):

$$\sigma = \frac{Q}{A}$$

(2) Electric Field (E):
The electric field between the plates is uniform and is given by:

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}$$

(3) Potential Difference (V :
The potential difference between the plates is related to the electric field by:

$$V = E \cdot d = \frac{Q \cdot d}{\varepsilon_0 A}$$

(4) Capacitance (C):
By definition, capacitance is:

$C = \frac{Q}{V} = \frac{Q}{\left(\frac{Q \cdot d}{\varepsilon_0 A}\right)} = \frac{\varepsilon_0 A}{d}$

(B) Effect of Dielectric Slab in Parallel Setup

Since the capacitors remain connected to the DC battery, the potential difference V across each capacitor remains constant. When a dielectric slab of constant K is introduced, the capacitance increases to $C' = K \cdot C$.

(i) Charge on each capacitor:

Initial charge: $Q = CV$

New charge: $Q' = C'V = (KC)V = KQ$

Result: The charge on each capacitor increases by a factor of K.

(ii) Energy stored in the capacitor:

Initial energy: $U = \frac{1}{2}CVV^2$

New energy: $U' = \frac{1}{2}C'V^2 = \frac{1}{2}(KC)V^2 = KU$

Result: The energy stored increases by a factor of K.

OR

(A) Electron Drift Velocity and Current Relation

• Attainment of Average Velocity:

In a conductor, free electrons move randomly with high thermal speeds, resulting in a net average velocity of zero. When an electric field $\vec{E}$ is applied, electrons experience a steady force $\vec{F} = -e\vec{E}$ and accelerate.

However, they continuously collide with the positive ions of the lattice. During each collision, they lose their gained kinetic energy and restart their acceleration.

This continuous process of acceleration and collision results in a steady, slow net average velocity opposite to the electric field direction called drift velocity (v_d). which is independent of time.

Relation Between Current (n) and Drift Velocity (v_d) :

Let a conductor have cross-sectional area A and a free electron density n (number of electrons per unit volume).

In a small time interval Δt, the electrons travel a distance $\Delta x = v_d \cdot \Delta t$.

Volume containing these moving electrons: $\Delta V = A \cdot \Delta x = A \cdot v_d \cdot \Delta t$

Total number of electrons in this volume: $\Delta N = n \cdot A \cdot v_d \cdot \Delta t$

Total charge passing through the cross section: $\Delta Q = \Delta N \cdot e = neAv_d \cdot \Delta t$

Since current $I = \frac{\Delta Q}{\Delta t}$:

$I = neAv_d$

(B) Conceptual and Numerical Problems

(i) Instantaneous Current:

When the circuit is closed, an electromagnetic field is established throughout the entire circuit almost instantaneously at the speed of light ($c \approx 3 \times 10^8$ m/s).

This field forces all free electrons across the entire loop to begin drifting simultaneously. Consequently, current flows immediately without waiting for a single electron to travel from one end to the other.

(ii) Ratio of Drift Velocities in Series:

When components are connected in series, the electric current **I** remains identical through both wires.

From the current formula: $v_d = \frac{I}{neA} = \frac{I}{ne(nr^2)}$

Since both wires are copper, n is constant, making $v_d \propto \frac{1}{r^2}$.

Given the radius ratio $r_1 : r_2 = 3:2$:

$\frac{v_{d1}}{v_{d2}} = \left(\frac{r_2}{r_1}\right)^2 = \left(\frac{2}{3}\right)^2 = \frac{4}{9}$

Result: The ratio of their drift velocities is 4:9.

33. **(A)** Derivation of Impedance and Phase Difference

Consider a series LCR circuit containing an inductor L_r capacitor C, and resistor R connected to an alternating voltage source:

$v = V_m \sin(\omega t)$

Let the alternating current flowing in the circuit at any instant be i.

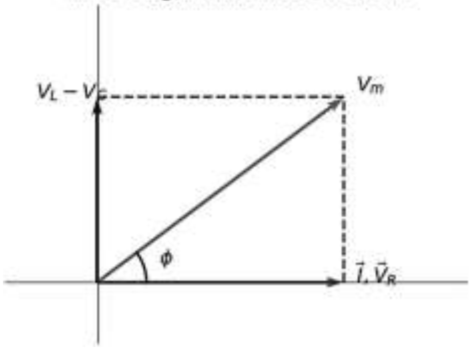
Phasor Diagram

In a series circuit, the same current flows through all components. We take current $\vec{I}$ as the reference phasor along the positive x -axis.

• Voltage across Resistance ($\vec{V}_R$): In phase with current $\vec{I}$.
• Voltage across Inductance $(\vec{V}_L)$: Leads current $\vec{I}$ by $\frac{\pi}{2}$ radians (90°).
• Voltage across Capacitance ($\vec{V}_C$): Lags current $\vec{I}$ by $\frac{\pi}{2}$ radians (90°).

Assuming $V_L > V_C$ the resultant of $\vec{V}_L$ and $\vec{V}_C$ is ($V_L - V_C$) pointing upwards along the y-axis.

Phasor Diagram for Series LCR Circuit

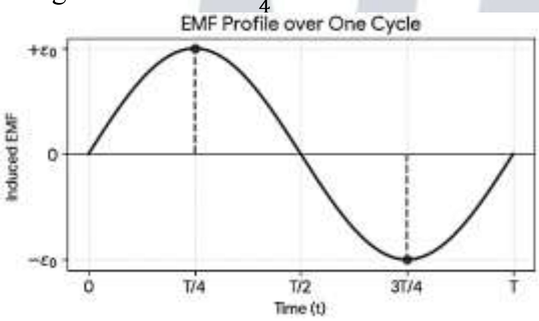


Expression for Impedance (Z)
From the right-angled triangle in the phasor diagram:
$V_m^2 = V_R^2 + (V_L - V_C)^2$
Substitute individual voltage amplitudes using Ohm's Law $(V_R = IR, V_L = IX_L, V_C = IX_C$:
$V_m^2 = (IR)^2 + (IX_L - IX_C)^2$
$V_m^2 = I^2[R^2 + (X_L - X_C)^2]$
$V_m = I\sqrt{R^2 + (X_L - X_C)^2}$
The total effective opposition to alternating current is Impedance (Z):
$Z = \frac{V_m}{I} = \sqrt{R^2 + (X_L - X_C)^2}$
Expression for Phase Difference (ϕ)
From the phasor triangle, the tangent of the phase angle ϕ is:
$\tan\phi = \frac{V_L - V_C}{V_R} = \frac{IX_L - IX_C}{IR}$
$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$
(B) Specific Conditions
(i) Condition for Minimum Impedance
The impedance is minimum at the resonance condition, where inductive reactance equals capacitive reactance:
$x_L = x_C \Longrightarrow \omega L = \frac{1}{\omega C}$
At this condition, minimum impedance equals pure resistance:
$Z_{min} = R$
(ii) Condition for Wattless Current
Wattless current flows when the average power consumed over a complete cycle is zero ($P_{avg} = 0$).
• Formula for power: $P_{avg} = V_{rms} I_{rms} \cos\phi = 0$
• This requires the power factor to be zero: $\cos\phi = 0 \Longrightarrow \phi = \frac{\pi}{2}(90°)$
Conditions:
(1) The circuit must be purely inductive ($R = 0, X_C = 0$) or purely capacitive ($R = 0$, $X_L = 0$).
(2) A completely resistance-less circuit.

OR

(i) AC Generator Overview
• Principle: Works on the principle of Faraday's Law of Electromagnetic Induction. When a coil rotates inside a uniform magnetic field, the magnetic flux linked with it changes continuously, inducing an electromotive force (emf) in the coil.
• Construction
(1) Field Magnets: Strong permanent magnets or electromagnets providing a uniform magnetic field.
(2) Armature: A rectangular coil (ABCD) wound over a soft iron core.
(3) Slip Rings: Two metallic rings (R_1, R_2) connected to the ends of the armature coil that rotate with it.

(4) Brushes: Two stationary carbon blocks (B_1, B_2) pressing against the slip rings to pass current to the external circuit.
• Working
• As the armature rotates, the magnetic flux changes continuously.
• During the first half-rotation, one side moves up and the other moves down, inducing a current in one direction (e.g., A → B → C → D).
• During the second half-rotation, positions reverse, reversing the direction of induced current. This produces alternating current.
(ii) Derivation of Induced EMF
Let:
• N = Number of turns in the coil
• A = Area of the coil
• B = Magnetic field strength
• $\theta = \omega t$ = Angle between the normal to the coil and magnetic field at time t
The magnetic flux Φ linked with the coil at any instant t :
$\Phi = NBA\cos\theta = NBA\cos(\omega t)$
According to Faraday's Law of Induction:
$$\varepsilon = -\frac{d\Phi}{dt} = -\frac{d}{dt}[NBA\cos(\omega t)]$$
$\varepsilon = -NBA(-\omega\sin(\omega t))$
$E = NBA\omega\sin(\omega t)$
Letting $\varepsilon_0 = NBA\omega$ represent the maximum (peak) emf:
$\varepsilon = \varepsilon_0\sin(\omega t)$
(iii) Time Intervals for Maximum EMF
The induced emf expression varies with time as $\varepsilon = \varepsilon_0\sin\left(\frac{2\pi}{T}t\right)$.
The emf is maximum $(\pm\varepsilon_0)$ when $\left|\sin\left(\frac{2\pi}{T}t\right)\right| = 1$.
$$\frac{2\pi}{T}t = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \ldots$$
Solving for time t within one complete cycle $(0 \leq t < T)$:
• Positive Peak: $t = \frac{T}{4}$
• Negative Peak: $t = \frac{3T}{4}$



34. (b) • Kinetic energy of the charged particle
Given:
$\vec{E} = E_0\hat{i}$
Force on charge q :
$F = qE_0$
Work done by electric field in moving through distance x :
$W = Fx = qE_0x$
Since the particle starts from rest, by work-energy theorem,
$\Delta K = W$
$K = qE_0x$
$K = qE_0x$
35. (c) • Induced emf in the rotating square loop
Given:
• Side = 50 cm = 0.5 m

• Area
$A = (0.5)^2 = 0.25\ \text{m}^2$
• $B = 3.0\ \text{T}$
• Rotation $= 90^\circ$
• Time $= 0.3\ \text{s}$
Initial flux:
$\phi_i = BA$
Final flux:
$\phi_f = 0$
Change in flux:
$\Delta\phi = BA = 3 \times 0.25 = 0.75\ \text{Wb}$
Induced emf:
$$e = \frac{\Delta\phi}{\Delta t} = \frac{0.75}{0.3} = 2.5\ \text{V}$$
$e = 2.5\ \text{V}$

36. **(a)** • Velocity of the electromagnetic wave
Given:
$B = 5 \times 10^{-8} \sin(3 \times 10^{10} t - 150x)\text{T}$
Compare with
$B = B_0 \sin(\omega t - kx)$
Thus,
$\omega = 3 \times 10^{10} \text{rad s}^{-1}$
$k = 150 \text{rad m}^{-1}$
Wave velocity:
$$v = \frac{\omega}{k} = \frac{3 \times 10^{10}}{150} = 2 \times 10^8\ \text{m s}^{-1}$$
$v = 2.0 \times 10^8\ \text{m s}^{-1}$

37. **(b)** Focal length of the lens combination
For lenses in contact:
$P = P_1 + P_2$
Plano-convex lens
$$\frac{1}{f_1} = (\mu - 1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{\mu - 1}{R}$$
Equi-concave lens
$$\frac{1}{f_2} = (\mu - 1)\left(\frac{-1}{R} - \frac{1}{R}\right) = -\frac{2(\mu - 1)}{R}$$
Hence
$$\frac{1}{f} = \frac{\mu - 1}{R} - \frac{2(\mu - 1)}{R} = -\frac{\mu - 1}{R}$$
$$f = -\frac{R}{\mu - 1}$$
$$f = -\frac{R}{\mu - 1}$$

38. **(a)** Phase difference for a bright fringe in YDSE
For constructive interference:
$\Delta\phi = 2n\pi$
where $n = 0, 1, 2, \ldots$
$\Delta\phi = 2n\pi$

39. **(a)** Telescope
Given:
$f_o = 144\ \text{cm}, f_e = 6\ \text{cm}$
Magnifying power:
$$M = \frac{f_o}{f_c} = \frac{144}{6} = 24$$
Length of telescope in normal adjustment:

$L = f_o + f_c = 144 + 6 = 150$ cm
$M = 24, L = 150$ cm

40. (a) • Total internal reflection does NOT occur in
• Brilliance of diamonds → due to TIR
• Optical fibre - due to TIR
• Reflecting prism → due to TIR
• Twinkling of stars → due to atmospheric refraction X
Twinkling of stars

41. (d) Photoelectric Effect
Given:
• $\lambda = 200$ mm
• Work function $\phi = 4.2\text{eV}$
Photon energy:
$$E = \frac{1240}{\lambda(\text{ nm})} = \frac{1240}{200} = 6.2\text{eV}$$
Maximum kinetic energy:
$K_{max} = E - \phi = 6.2 - 4.2 = 2.0\text{eV}$
$K_{max} = 2.0\text{eV}$

42. (c) • Proton and alpha particle have equal momentum
For equal momentum p,
$$K = \frac{p^2}{2m}$$
Hence
$$\frac{E_p}{E_a} = \frac{m_a}{m_p} = \frac{4m_p}{m_p} = 4$$
Also,
$$\lambda = \frac{h}{p}$$
Since momentum is equal,
$\lambda_p = \lambda_a$
$$\frac{\lambda_p}{\lambda_a} = 1$$
Therefore,
$$\frac{E_p}{E_a} = 4, \frac{\lambda_p}{\lambda_a} = 1$$

43. (b) Ratio of nuclear radii
Nuclear radius:
$R = R_0 A^{1/3}$
Therefore,
$$\frac{r_1}{r_2} = \left(\frac{64}{27}\right)^{1/3} = \frac{4}{3}$$
$$\frac{r_1}{r_2} = \frac{4}{3}$$

44. (c) • Forward bias resistance of diode
Given:
$\Delta V = 1.0 - 0.8 = 0.2$ V
$\Delta I = 2.0 \text{ mA} = 2 \times 10^{-3}$ A
Dynamic resistance:
$$r = \frac{\Delta V}{\Delta I} = \frac{0.2}{2 \times 10^{-3}} = 100\Omega$$
$r = 100\Omega$

45. (a) • Minority carrier injection occurs during
In a fonward-biased p-n junction:
• Electrons from n-side enter p-side.

• Holes from p-side enter n-side.
These become minority carriers in the new region, hence the process is called minority carrier injection.
Forward biasing

46. **(a)** • Assertion is True: Interchanging the battery and galvanometer positions converts the balance equation from $\frac{P}{Q} = \frac{R}{S}$ to $\frac{P}{R} = \frac{Q}{S}$.

• Reason is True: Mathematically, $\frac{P}{Q} = \frac{R}{S}$ is equivalent to $\frac{P}{R} = \frac{Q}{S}$ since both give $P \cdot S = Q \cdot R$

• Explanation matches: The Reason correctly shows why the balance remains unchanged.

47. **(d)** • Assertion is False: The soft iron core has high magnetic permeability, which significantly intensifies the strength of the magnetic field in addition to making it radial.

• Reason is False: In a radial magnetic field, the magnetic field lines are always parallel to the plane of the coil (perpendicular to its area vector) to maximize torque.

48. **(b)** • Assertion is True: Photoelectric current is directly proportional to the intensity of incident light.

• Reason is True: Stopping potential depends only on the frequency of the light, making it independent of intensity.

• Explanation does not match: The Reason is a true independent statement but does not explain why the current depends on intensity.

49. **(d)** • Assertion is False: Nuclear forces become strongly repulsive at extremely short distances (less than 0.5 fm) to prevent the nucleus from collapsing.

• Reason is False: The nuclear force holding nucleons together is the strong nuclear force, which is the strongest fundamental force in nature, not a weak force.

50. **(A)** Given: $E_1 = 6$ V, internal resistance $r_1 = 1\Omega$

$E_2 = 4$ V, internal resistance $r_2 = 3\Omega$

Net current in the loop.

$E_{net} = 6 - 4$
$= 2$ V
$R_{total} = 1 + 3\Omega$
$= 4\Omega$
$I = \frac{E_{net}}{R_{total}}$
$= \frac{2}{4}$
$= 0.5$ A

Potential difference between B and C

Since current enters the positive terminal, the cell is being charged.

$V_{BC} = E - Ir$
$= 4 - (0.5 \times 3)$
$= 4 - 1.5$
$= 2.5$ V

OR

(B) Given: $E = 21$ V
$r = 3\Omega$
$I = 3$ A

(i) Resistance of external resistor

$I = \frac{E}{R + r}$
$3 = \frac{21}{R + 3}$
$3 = \frac{21}{R + 3}$
$R + 3 = \frac{21}{7}$
$R + 3 = 7$
$R = 7 - 4$

$= 3\Omega$

(ii) Terminal voltage

$V = E - Ir$

$= 21 - (3 \times 3)$

$= 21 - 9$

$= 12\ V$

51. Diffraction of Sound vs. Light

Diffraction is the bending of waves around the corners of an obstacle or through an aperture. The extent of diffraction depends on the ratio of the wavelength (λ) of the wave to the size of the obstacle/aperture (a). Significant diffraction occurs when $\lambda \approx a$.

• Sound Waves: Have wavelengths ranging from a few centimeters to several meters. These sizes are comparable to common objects (doors, walls, furniture) in our daily environment, making the diffraction of sound very common.

• Light Waves: Have extremely small wavelengths (in the order of $400 - 700$ nm). To observe significant diffraction of light, the obstacle size must be similarly microscopic. Therefore, light does not bend noticeably around ordinary macroscopic objects

52. Atomic nuclei consist of protons and neutrons (collectively called nucleons). The total mass of a nucleus is always less than the sum of the masses of its individual nucleons. This difference gives rise to the ideas of mass defect and binding energy.

(1) Mass Defect: Mass defect is the difference between the combined mass of all free nucleons and the actual mass of the nucleus.

$\Delta m = \left(Zm_p + Nm_n\right) - M_{\text{nucleus}}$

(2) Binding Energy: Binding energy is the energy required to completely separate a nucleus into its individual nucleons. It is a measure of the nuclear stability of a nucleus.

(i) Higher binding energy means the nucleus is more stable.

(ii) Lower binding energy means the nucleus is less stable and easier to break apart.

Relation Between Mass Defect and Binding Energy:

• The mass defect is directly related to binding energy through Einstein's mass-energy equivalence principle ($E = mc^2$).

• The energy equivalent of the mass defect is what we call the binding energy:

Binding energy $= \Delta mc^2$

• If the mass defect is measured in atomic mass units (u), then it can be converted into MeV (Mega electron volts):

$1u = 931.5 MeV$

Thus, the missing mass (mass defect) in the nucleus is transformed into binding energy, which holds the nucleus together.

53. Ratio of de Broglie wavelengths

A particle of mass M at rest splits into two particles of masses m_1 and m_2.

Since the initial momentum is zero, by conservation of momentum:

$m_1 v_1 = m_2 v_2$

Hence the magnitudes of momenta are equal:

$p_1 = p_2$

The de Broglie wavelength is

$\lambda = \frac{h}{p}$

Therefore,

$\lambda_1 = \frac{h}{p_1}, \lambda_2 = \frac{h}{p_2}$

Since $p_1 = p_2$,

$\lambda_1 = \lambda_2$

Thus,

$\frac{\lambda_1}{\lambda_2} = 1$

or

$\lambda_1 : \lambda_2 = 1:1$

54. Creation of charge carriers in an intrinsic semiconductor
An intrinsic semiconductor is a pure semiconductor such as silicon or germanium.
At absolute zero, all electrons are bound in covalent bonds and no free charge carriers exist.
When the temperature is increased, some valence electrons gain sufficient thermal energy to break their covalent bonds and move to the conduction band.
As a result:
• A free electron is created in the conduction band.
• A hole is left behind in the valence band.
Thus, charge carriers are produced in electron-hole pairs.
Thermal energy breaks covalent bonds, creating equal numbers of free electrons and holes.
Diagram (conceptual)

$$\text{Valence Band} \xrightarrow{\text{thermal energy}} \text{Conduction Band}$$

Electron promoted to conduction band ⇒ one electron + one hole generated.
Hence, in an intrinsic semiconductor:

$$n_e = n_h$$

where n_e is the electron concentration and n_h is the hole concentration.

55. **(A)** Relation between drift velocity (v_d) and current (I)
Consider a conductor of:
• Cross-sectional area A
• Free electron density n (electrons per unit volume)
• Electron charge e
• Drift velocity v_d
In time dt, electrons drift through a distance

$$dx = v_d dt$$

Volume of conductor crossed:

$$dV = Av_d dt$$

Number of electrons crossing any section:

$$dN = nAv_d dt$$

Charge crossing the section:

$$dq = dN \cdot e = nAev_d dt$$

Current is

$$I = \frac{dq}{dt}$$

Hence,

$$I = nAev_d$$

or $v_d = \frac{I}{nAe}$

(B) Effect of doubling the length

$$v_d = \frac{I}{nAe}$$

Since

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

and

$$R = \rho\frac{L}{A}$$

If the length is doubled:

$$L' = 2L$$

Then $R' = 2R$
With applied voltage constant,

$$I' = \frac{V}{R'} = \frac{V}{2R} = \frac{I}{2}$$

Therefore,

$$v_d' = \frac{I'}{nAe} = \frac{1}{2}v_d$$

Drift velocity becomes half.

56. **(A)** Given: Number of turns of the coil, $N = 30$

Radius of the coil, $r = 8 \text{ cm} = 0.08 \text{ m}$

Current in the coil, $I = 6 \text{ A}$

Magnetic field strength, $B = 1.0 \text{ T}$

Formula: Torque on a Current Loop $(\tau) = NIAB \sin\theta$

The angle between the magnetic field and the plane of the coil is 30%. However, the formula requires the angle between the magnetic field and the normal to the coil, so:

$\theta = 90^\circ - 30^\circ$

$= 60^\circ$

For a circular coil, the area A is given by:

$A = \pi r^2$

$= \pi(0.08)^2$

$= \frac{22}{7} \times 0.0064$

$= \frac{0.1408}{7}$

$= 0.0201 \text{ m}^2$

$\tau = NIAB\sin\theta$

$= NIAB\sin 60^\circ$

$= 30 \times 6 \times 0.0201 \times 1 \times \frac{\sqrt{3}}{2}$

$= 180 \times 0.0201 \times 0.866$

$= 3.13 \text{ N.m}$

This is the external torque required to hold the coil in position.

Effect of irregular planar coil to the torque τ depends on:

$\tau = NIAB\sin\theta$

The shape of the coil does not affect the torque, as long as it encloses the same area. If the circular coil is replaced with an irregular planar coil that encloses the same area, the torque will remain unchanged.

OR

(B) Given: Mass of the alpha particle, $m = 6.4 \times 10^{-27} \text{ kg}$

Charge of the alpha particle, $q = 3.2 \times 10^{-19} \text{C}$

Energy of the alpha particle, $E = 8.0 \text{MeV}$

Magnetic field strength, $B = 0.5 \text{ T}$

Formula: Magnetic force provides centripetal force:

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

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

Convert energy to joules

$E = 8.0 \text{MeV}$

$= 8 \times 10^6 \times 1.6 \times 10^{-19}$

$E = 1.28 \times 10^{-12} \text{ J}$

The total energy is related to the kinetic energy K.E. (since the particle starts from rest):

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

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

$v = \sqrt{\frac{2E}{m}}$

$= \sqrt{\frac{2 \times 1.28 \times 10^{-12}}{6.4 \times 10^{-27}}}$

$= \sqrt{\dfrac{2.56 \times 10^{-12} \times 10^{27}}{6.4}}$

$= \sqrt{\dfrac{2.56 \times 10^{15}}{6.4}}$

$= \sqrt{(0.4 \times 10^{15})}$

$= \sqrt{4 \times 10^{14}}$

$= 2 \times 10^{7}$ m/s

The radius r of the circular path of a charged particle moving in a magnetic field is given by the formula:

$r = \dfrac{mv}{qB}$

$= \dfrac{(6.4 \times 10^{-27}) \times (2 \times 10^{7})}{(3.2 \times 10^{-19}) \times (0.5)}$

$= \dfrac{12.8 \times 10^{-20}}{1.6 \times 10^{-19}}$

$= \dfrac{1.28 \times 10^{-19}}{1.6 \times 10^{-19}}$

$= 0.8$ m

(i) Helical path: For the particle to describe a helical path, the velocity must have both parallel and perpendicular components relative to the magnetic field. That means:

$v_1 \neq 0, v_{||} \neq 0$

In this case, the particle moves along a spiral trajectory because the magnetic field affects only the perpendicular component of its velocity.

(ii) Straight undeviated path: If the velocity is parallel to the magnetic field ($\vec{v} || \dot{B}$), then there is no magnetic force acting on the particle because the magnetic force is proportional to the perpendicular component of the velocity relative to the magnetic field. In this case:

$\dot{v} || \dot{B} \Rightarrow$ No magnetic force, and the particle moves in a straight line.

57. (A) Behaviour of an Inductor

(i) When connected to a DC source

For DC , frequency $f = 0$.

$X_L = 2\pi f L = 0$

• Initially, the inductor opposes the increase of current due to self-induced emf.
• After some time, current becomes steady and self-induced emf becomes zero.
• The inductor then behaves like a short circuit (ideal case).

An inductor allows steady DC to pass with negligible opposition.

(ii) When connected to a high-frequency AC source

Inductive reactance is

$X_L = 2\pi f L$

As frequency increases,

$X_L \propto f$

• The opposition offered by the inductor increases with frequency-
• For very high frequency AC, X_L becomes very large.

An inductor offers large opposition to high-frequency AC and behaves almost like an open circuit.

(B) Phase relation between current and voltage

For an ideal inductor,

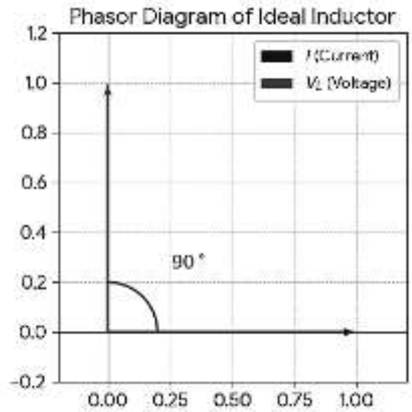
$V = L\dfrac{dI}{dt}$

Hence, the voltage reaches its maximum value one-quarter cycle before the current.

Voltage leads current by 90°

or

Current lags voltage by 90°



• Current I is taken as the reference phasor.

• Voltage V_L leads current by 90°.

$$\phi = \frac{\pi}{2} = 90^\circ$$

• Result: In an ideal inductor, current lags voltage by 90°.

58. **(A)** An electromagnetic (EM) wave consists of time-varying electric and magnetic fields that propagate through space, perpendicular to each other and the direction of wave propagation.

Variation of $\vec{E}$ and $\vec{B}$:

(1) Sinusoidal Oscillations: Both the electric field $\vec{E}$ and the magnetic field $\vec{B}$ oscillate sinusoidally as the wave propagates.

(2) Mutual Perpendicularity: The electric field $\vec{E}$ and the magnetic field $\vec{B}$ are mutually perpendicular to each other.

(3) Perpendicular to Propagation: Both $\vec{E}$ and $\vec{B}$ are perpendicular to the direction of wave propagation. When the wave propagates along the x -axis:

• The electric field $\vec{E}$ oscillates along the y-axis.

• The magnetic field $\vec{E}$ oscillates along the z-axis.

Mathematically, the wave can be expressed as:

$E = E_0 \sin(kx - \omega t)$

$B = B_0 \sin(kx - \omega t)$

Two Important Characteristics of EM Waves:

(1) Transverse Nature: EM waves are transverse waves, meaning the electric and magnetic fields oscillate perpendicular to the direction of propagation.

(2) In-phase Oscillations: The electric field $\vec{E}$ and magnetic field $\vec{B}$ reach their maxima and minima simultaneously.

Other Properties of EM Waves:

• Do not require a material medium: EM waves can propagate through a vacuum, unlike mechanical waves, which require a medium.

• Carry energy and momentum: EM waves carry energy and momentum, allowing them to transfer both through space.

(B) Maxwell obtained the wave equation for electric and magnetic fields in free space as:

$$\nabla^2 E = \mu_0 \varepsilon_0 \frac{\partial^2 E}{\partial t^2}$$

This equation is comparable to the general wave equation:

$$\nabla^2 \psi = \frac{1}{v^2} \frac{\partial^2 \psi}{\partial t^2}$$

On comparing the two equations, we get:

$$\frac{1}{v^2} = \mu_0 \varepsilon_0$$

$$v = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

Substituting the values:

$\mu_0 = 4\pi \times 10^{-7} \text{Tm A}^{-1}$

$\varepsilon_0 = 8.854 \times 10^{-12} C^2\ N^{-1}\ m^{-2}$

$$v = \frac{1}{\sqrt{(4\pi \times 10^{-7})(8.85 \times 10^{-12})}}$$

$= 3 \times 10^8$

Hence, the speed of electromagnetic waves in free space is:

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

This result shows that electromagnetic waves travel at the speed of light, thereby confirming that light is electromagnetic in nature.

59. The angle at which the ray will emerge into the air from the water-air surface is 90° (grazing emergence).

Step-by-Step Derivation

(1) Find the Initial Incident Angle

Initially, the light ray is incident on the horizontal glass-air surface at the critical angle (θ_c).

Refractive index of glass $(\mu_g) = \frac{3}{2}$

Refractive index of air $(\mu_\alpha) = 1$

Using the formula for the critical angle:

$$\sin\theta_c = \frac{\mu_a}{\mu_g} = \frac{1}{3/2} = \frac{2}{3}$$

Therefore, the angle of incidence (i) inside the glass slab is such that $\sin i = \frac{2}{3}$.

(2) Refraction at the Glass-Water Interface

When a horizontal layer of water ($\mu_w = \frac{4}{3}$) is added, the ray meets the glass-water boundary at the same incident angle i. Let r be the angle of refraction in water.

Applying Snell's Law at the glass-water interface:

$\mu_g \sin i = \mu_m \sin r$

Substitute the known values:

$$\left(\frac{3}{2}\right)\left(\frac{2}{3}\right) = \frac{4}{3}\sin r$$

$$1 = \frac{4}{3}\sin r \Rightarrow \sin r = \frac{3}{4}$$

(3)Refraction at the Water-Air Interface

Since the water layer is horizontal and parallel to the glass slab, the angle of incidence at the water-air boundary is also equal to r. Let e be the angle of emergence into the air.

Applying Snell's Law at the water-air interface:

$\mu_w \sin r = \mu_a \sin e$

Substitute the values:

$$\left(\frac{4}{3}\right)\left(\frac{3}{4}\right) = 1 \cdot \sin e$$

$1 = \sin e$

Since sine = 1 , we find:

$e = 90°$

60.

Basis	Nuclear Fission	Nuclear Fusion
Definition	Splitting of a heavy nucleus into two or more lighter nuclei.	A combination of two light nuclei to form a heavier nucleus.

Nuclei involved	Heavy nuclei like uranium or plutonium are involved.	Light nuclei like hydrogen isotopes are involved.
Energy release	A large amount of energy is released.	An even greater amount of energy is released than in fission.
Conditions required	It occurs at comparatively lower temperatures and can be initiated by neutrons.	It requires extremely high temperature and pressure.
Chain reaction	Nuclear fission can produce a chain reaction, which is used in nuclear reactors.	Nuclear fusion does not occur as a self-sustaining chain reaction in the same way.
By-products	Produces radioactive waste.	Produces very little radioactive waste.

Example of Nuclear Fission:

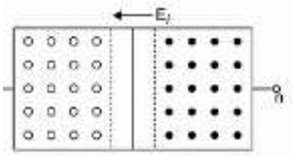
$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \longrightarrow {}^{141}_{56}\mathrm{Ba} + {}^{92}_{36}\mathrm{Kr} + 3\,{}^{1}_{0}\mathrm{n} + \text{ Enegry}$

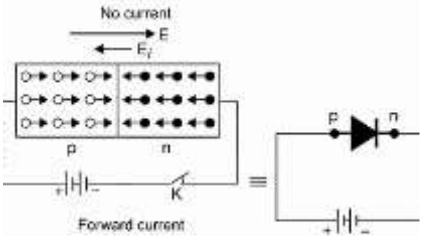
Example of Nuclear Fusion:

$^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + \text{ Energy}$

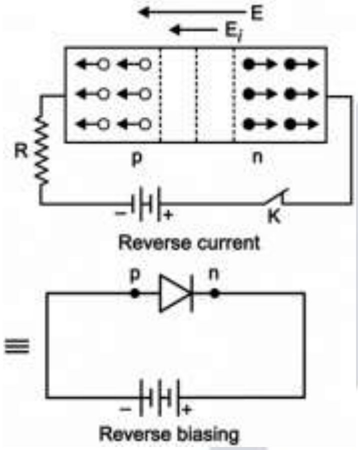
61. Forward biasing

• The positive terminal of the power supply is connected to the p-type material (anode), and the negative terminal is connected to the n-type material (cathode). In this setup, the positive terminal of the battery is connected to the p-end of the crystal and the negative terminal to the n-end, creating an external electric field E that opposes the internal field E_i, as illustrated in the diagram. The external field E is significantly stronger than the internal field E_i.





• Reverse biasing
• The positive terminal of the power supply is connected to the n-type material (cathode), and the negative terminal is connected to the ptype material (anode). This configuration creates an external field that aids the internal field E_1, as shown in the diagram. Under this biasing, the holes in the p-region and the electrons in the n-region are pushed away from the junction, causing the depletion layer to widen and increasing the potential barrier, thus stopping the current flow.



62. (i) (d) For capacitors in series:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$
$$= \frac{1}{3} + \frac{1}{6}$$
$$= \frac{2+1}{6}$$
$$= \frac{3}{6}$$
$$C_{eq} = 2\mu\ F$$

(ii) (d)
Explanation:
After a long time in a DC circuit:
• Capacitors act as open circuits.
• No steady current passes through the capacitor branch.
Therefore, no current flows through the loop containing the 10Ω resistor.

(iii) (d)
Explanation:
Because capacitors block DC current, no current flows through the resistors, so there is no voltage drop across them.
As a result, the entire battery voltage appears across points A and B .
$V_{AB} = 3\ V$

(iv) (A) (a)

Explanation:
For capacitors in series: The charge on each capacitor is the same.
$Q = C_{eq} V$
$= 2\mu F \times 3 V$
$= 6\mu C$
Hence, the charge on the $6\mu F$ capacitor is $6\mu C$.

OR

(B) (b)
Cutting the wire disconnects the branch that includes the capacitors.
This raises the effective resistance in the circuit loop, which lowers the current. Therefore, the current decreases.

63. (i) (a) Kinetic energy gained:
$K = qV$
$K_1 = 1qV \quad \ldots(i)$
$K_2 = 2qV \quad \ldots(ii)$
Equation (i) and (ii) we get,
$\left(\frac{K_1}{K_2}\right) = \frac{qV}{2qV}$
$= \frac{1}{2}$

(ii) (a)
Radius in magnetic field:
$r = \frac{mv}{qB}$
Using $K = \frac{1}{2}mv^2$
$v = \sqrt{\frac{2K}{m}}$
$r = \frac{m}{qB}\sqrt{\frac{2K}{m}}$
$= \sqrt{\frac{2mK}{qB}}$
$K = qV$
$r\alpha\frac{\sqrt{m}}{q}$
$\frac{r_1}{r_2} = \sqrt{\frac{mn_1q_2}{m_2q_1}}$
$= \sqrt{\frac{m \cdot 2q}{(m/2) \cdot q}}$
$= \sqrt{\frac{2m}{m/2}}$
$= \sqrt{4}$
$= \sqrt{2}$
$\frac{r_1}{r_2} = \frac{1}{\sqrt{2}}$

(iii) (c)
Magnetic force: $\vec{F} = q(\vec{v} \times \vec{B})$
Since the charges are of opposite signs, the direction of the magnetic force differs for each particle.
A negative charge experiences force in the direction opposite to that given by the right-hand rule, whereas a positive charge follows the right-hand rule.

Therefore, the two particles move in opposite directions.

(iv) (A) (a)

Time period in magnetic field:

$T = \frac{2\pi m}{qB}$

$T \alpha \frac{m}{q}$

$= \frac{m}{q}$

$\frac{T_1}{T_2} = 4$

$T_1 = 4\ s$ ....(Given)

$T_2 = 1\ s$

OR

(B) (b)

Momentum: $p = mv$

Using $K = \frac{1}{2}mv^2$

$= qV$

$p = \sqrt{2mK}$

Since $K \propto q$,

$p \propto \sqrt{mq}$

$p_1 = \sqrt{2m \cdot qV}$ .....(i)

$p_2 = \sqrt{\frac{m}{2} \cdot 2qV}$ ......(ii)

Equations (i) and (ii) we get,

$\frac{p_1}{p_2} = 1$

$\therefore p_1 = p_2$

64. (A) (i) Core Principle:

The electric potential V at a distance r from a point charge Q is given by:

$V = \frac{kQ}{r}$

$= (kQ) \cdot \frac{1}{r}$

This equation is in the form $y = mx$, where $y = V$ and $x = \frac{1}{r}$.

Therefore, the slope (m) of the line represents kQ .

(I) Nature of the Charges Q_1 and Q_2 :

Charge Q_1, (Line OA): This line lies in the positive V region (above the horizontal axis). Since the potential is positive, Q_1 is a positive charge.

Charge Q_2 (Line OB): This line lies in the negative V region (below the horizontal axis). Since the potential is negative, Q_2 is a negative charge.

(II) The slope of a line on a graph is equal to the tangent of the angle $(\tan\theta)$ it makes with the positive horizontal axis.

$\text{Slope}_1 = kQ_1$

$= \tan(60°)$

$= \sqrt{3}$

Since line OB is below the axis, it represents a negative slope:

$\text{Slope}_2 = kQ_2$

$= \tan(-30°)$

$= -\frac{1}{\sqrt{3}}$

The ratio of the charges:

$\left(\frac{Q_1}{Q_2}\right) = \frac{kQ_1}{kQ_2}$
$= \frac{\tan 60^\circ}{-\tan 30^\circ}$
$= \frac{\sqrt{3}}{-\frac{1}{\sqrt{3}}}$
$= -(\sqrt{3} \times \sqrt{3})$
$= -3$
(ii) Given: $q_1 = -2\mu C$
$= -2 \times 10^{-6} C$
$q_2 = 5\mu C$
$= 5 \times 10^{-6} C$
$r = |x_2 - x_1|$
$= |30 - (-30)| cm$
$= 0.60$ cm
$= 0.6$ m
$A = 9 \times 10^5 Nm^2C^{-1}$
$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ N^{-1}\ m^2C^{-2}$
Formula: $U_{int} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$
$= \frac{4\pi\varepsilon_0 \times q_1 q_2}{r}$
$= \frac{9 \times 10^9 \times (-2 \times 10^{-6}) \times (5 \times 10^{-6})}{0.6}$
$= \frac{-90 \times 10^{-3}}{0.6}$
$= -150 \times 10^{-3}$
$= -0.15$ J
The relationship between electric field and potential is $V = -\int \vec{E} \cdot d\vec{r}$
Calculating the potential at each position $(A = 9 \times 10^5 Nm^2C^{-1})$
$E = \frac{A}{x^2}$
$V(x) = -\int \frac{A}{x^2} dx$
$= \frac{A}{x}$
$V(x_1) = \frac{9 \times 10^5}{-0.30}$
$= -3 \times 10^6$ V
$V(x_2) = \frac{9 \times 10^5}{0.30}$
$= 3 \times 10^6$ V
In an external field, the energy of each charge in the field is $U = qV$.
$U_1 = q_1 V_1$
$= (-2 \times 10^{-6}) \times (-3 \times 10^6)$
$= 6$ J
$U_2 = q_2 V_2$
$= (5 \times 10^6) \times (3 \times 10^6)$
$= 15$ J
Total Potential Energy
$U_{total} = U_1 + U_2 + U_{int}$
$= 6 + 15 + (-0.15)$
$= 20.85$ J

OR

(B) (i) Given: $\lambda_1 = -\lambda$

$\lambda_2 = 3\lambda$

The force per unit length between two infinitely long straight parallel wires with linear charge densities λ_1 and λ_2 is given by:

$$f = \frac{F}{L} = \frac{1}{2\pi\varepsilon_0}\frac{\lambda_1\lambda_2}{r}$$

$$= \frac{1}{2\pi\varepsilon_0}\frac{(-\lambda)(3\lambda)}{r}$$

$$= \frac{1}{2\pi\varepsilon_0}\frac{-3\lambda^2}{r}$$

$$= -\frac{3\lambda^2}{2\pi\varepsilon_0 r}$$

Taking the absolute value for the magnitude:

$$= \frac{3\lambda^2}{2\pi\varepsilon_0 r}$$

Since the charges have opposite signs (λ_1 is negative and λ_2 is positive), the force is attractive.

(ii) Given: Point charge at center $= +2q$

Inner sphere $(r_1) = Q$

Outer sphere $(r_2, r_3) = -3q$

(I) Electric Flux (Gauss Law): The electric flux through a Gaussian surface is determined by the total enclosed charge q.

$$\Phi = \frac{q_{esclosed}}{\varepsilon_0}$$

(1) For $x < r_1$: The only charge enclosed is the point charge at the center (+2q).

$$\Phi = \frac{2q}{\varepsilon_0}$$

(2) For $r_1 < x < r_2$: The enclosed charge is the point charge (2q) plus the total charge on the inner sphere (Q).

$$\Phi = \frac{Q + 2q}{\varepsilon_0}$$

(II) Electric Field (E): The electric field at a distance x from the centre is given by

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q_{enclosed}}{x^2}$$

(1) For $x > r_3$: The Gaussian surface encloses all charges: the point charge 2q, the inner sphere charge Q, and the outer shell charge $-3q$.

$$q_{enclosed} = 2q + Q + (-3q)$$

$$= Q - q$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q - q}{x^2}$$

$$= \frac{Q - q}{4\pi\varepsilon_0 x^2}$$

(2) For $r_1 < x < r_2$: The enclosed charge is the point charge 2q and the charge Q on the inner sphere.

$$q_{enclosed} = 2q + Q$$

$$= Q + 2q$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q + 2q}{x^2}$$

$$= \frac{Q + 2q}{4\pi\varepsilon_0 x^2}$$

(III) Surface Charge Density (σ)

$$\sigma = \frac{\text{Induced Charge}}{\text{Surface Area}}$$

(1) Inner surface of sphere (r_1): To make the field zero within the conducting wall of the sphere, the charge on its inner surface must exactly neutralize the point charge 2q at the centre.

Induced charge is $-2q$.

$\sigma_{r_1} = \dfrac{-2q}{4\pi r_1^2}$

$= -\dfrac{q}{2\pi r_1^2}$

(2) Inner surface of shell (r_2): To make the field zero within the conducting shell, the charge on its inner surface must neutralize the total charge inside it (the point charge $2q$ and the total charge Q on the inner sphere).

Induced charge is $-(Q+2q)$.

$\sigma_{r_2} = \dfrac{-Q+2q}{4\pi r_2^2}$

65. (A) (i) The brightness of the bulb depends on the current flowing in the circuit.

The inductive reactance is given by:

$XL = \omega L$

$= 2\pi fL$

(I) When an iron bar is inserted inside the coil:

• Inserting an iron core increases the inductance L .

• As a result, the inductive reactance X_L increases.

• This increases the total impedance of the circuit, causing the current to decrease.

• Because the bulb's brightness depends on current, the bulb glows less brightly (its brightness decreases).

(II) When the frequency is decreased:

From the relation $XL = 2\pi fL$

• If the frequency f decreases, the inductive reactance X_L decreases.

• Lower reactance reduces the opposition to current, so the current increases.

• As a result, the bulb glows more brightly (its brightness increases).

(ii) Given: $V = 280\sin(100\pi t)$

$V_0 = 280\ V$

$\omega = 100\pi$

(I) Inductive Reactance $(X_D) = \omega L$

$= 100\pi \times \dfrac{5}{\pi}$

$= 500\Omega$

Capacitive reactance $(X_C) = \frac{1}{\omega C}$

$= \dfrac{1}{100\pi \times \left(\dfrac{50}{\pi} \times 10^{-6}\right)}$

$= \dfrac{10^6}{5000}$

$= 200\Omega$

Net reactance $(X) = X_L - X_C$

$= 500 - 200$

$= 300\Omega$

Impedance $(Z) = \sqrt{R^2 + X^2}$

$= \sqrt{400^2 + 300^2}$

$= \sqrt{160000 + 90000}$

$= \sqrt{250000}$

$= 500\Omega$

(II)

$V_{rms} = \dfrac{V_0}{\sqrt{2}}$

$= \dfrac{280}{1.4}$

$= 200\ V$

$I_{rms} = \dfrac{V_{rms}}{Z}$

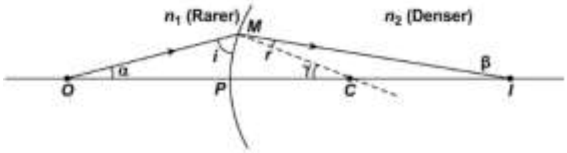
$= \frac{200}{500}$
$= 0.4$ A
(III)
$\cos\phi = \frac{R}{Z}$
$= \frac{100}{500}$
$= 0.8$

OR

(B) (i) Lenz's Law
Lenz's Law:
The direction of induced emf (or induced current) is such that it opposes the change in magnetic flux that produces it.
Induced emf always opposes the cause producing it.
Mathematically,
$e = -\frac{d\phi}{dt}$
The negative sign represents Lenz's law.
Relation with Law of Conservation of Energy
If the induced current aided the change in magnetic flux instead of opposing it, the flux would increase further and produce more induced current automatically. Energy would then be produced without any external work.
Since this is impossible, the induced current opposes the change in flux. Therefore external work has to be done to produce the induced emf.
Hence,
Lenz's law is a consequence of the law of conservation of energy.
(ii) Dimensional Formula of Self-Inductance
Using
$e = L\frac{dI}{dt}$
$L = \frac{e}{dI/dt}$
Dimensions of emf:
$[e] = ML^2T^{-3}A^{-1}$
Therefore,
$[L] = \frac{ML^2T^{-3}A^{-1}}{AT^{-1}} = ML^2T^{-2}A^{-2}$
$[L] = ML^2T^{-2}A^{-2}$
Numerical
Given:
$I_1 = 8.0$ A, $I_2 = 2.0$ A
$\Delta t = 0.6$ s
$e = 50$ V
Using
$e = L\frac{\Delta I}{\Delta t}$
$L = \frac{e\Delta t}{\Delta I}$
$L = \frac{50 \times 0.6}{8 - 2}$
$L = \frac{30}{6}$
$L = 5H$

66. (A) (i) For a point object placed in a rarer medium (n_1) in front of a convex spherical surface of a denser medium (n_2), the relationship between object distance (u), image distance (v), and radius of curvature (R) is given by:

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

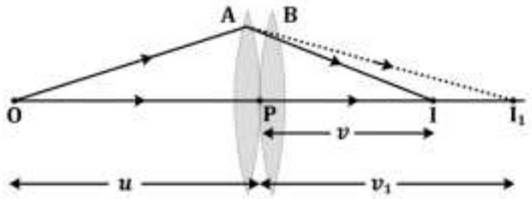


In △ OMC, the exterior angle is equal to the sum of the interior opposite angles:
$i=\alpha+\gamma$
the angle
In △ MIC, is the exterior angle:
$\gamma=r+\beta$
$r=\gamma-\beta$
According to Snell's Law:
$n_1 \sin i=n_2 \sin r$
For small angles, $\sin\theta \approx \theta$ (in radians):
$n_1 i=n_2 r$
Substituting equations (1) and (2) into this:
$n_1(\alpha+\gamma)=n_2(\gamma-\beta)$
$n_1\alpha+n_1\gamma=n_2\gamma-n_2\beta$
$n_1\alpha+n_2\beta=(n_2-n_1)\gamma$
Since the aperture is small, we can approximate the angles using the tangent (where MP is the perpendicular arc/height):
$\alpha \approx \frac{MP}{PO}$
$\beta \approx \frac{MP}{PI}$
$\gamma \approx \frac{MP}{PC}$
Using the New Cartesian Sign Convention:
Object distance PO $=-u$
Image distance PI = +v
Radius of curvature PC $=+R$
Substituting these into Equation (3):
$$n_1\left(\frac{MP}{-u}\right)+n_2\left(\frac{MP}{v}\right)=(n_2-n_1)\left(\frac{MP}{R}\right)$$
Dividing throughout by MP , we get the final relation:
$$\frac{n_2}{v}-\frac{n_1}{u}=\frac{n_2-n_1}{R}$$
(ii) Given: Focal length (f) $=+20$ cm
Object distance (u) $=-30$ cm
Formula: $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$
$\frac{1}{v}-\frac{1}{-30}=\frac{1}{20}$
$\frac{1}{v}+\frac{1}{30}=\frac{1}{20}$
$\frac{1}{v}=\frac{1}{20}-\frac{1}{30}$
$\frac{1}{v}=\frac{3-2}{60}$
$\frac{1}{v}=\frac{1}{60}$
$v=+60$ cm
Magnification (m) $=\frac{v}{u}$
$=\frac{60}{-30}$

$= -2$

OR

(B) (i)



• Two thin lenses, A and B (focal lengths f_1, f_2), are placed in contact with a common optical center P.
Lens A forms an image (I_1) of the object O.
This image I_1 acts as a virtual object for the second lens B .
Lens B then forms the final image at I.
Using the lens formula:

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

For lens A , the object distance is u , and the image distance is v_1.

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1} \qquad \ldots(i)$$

For the second lens, the image I_1 produced by the first lens serves as a virtual object. For lens B, the object distance is v_1, and the final image distance is v :

$$\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2} \qquad \ldots.(ii)$$

Adding equation (i) and equation (ii):

$$\left(\frac{1}{v_1} - \frac{1}{u}\right) + \left(\frac{1}{v} - \frac{1}{v_1}\right) = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2} \qquad \ldots.(iii)$$

If the combination is replaced by a single lens of focal length F hat forms an image of the same object at the same position, then:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{F}$$

Comparing this with equation (iii), we get:

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

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

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

In terms of power, the equation can be written as

$$P = \frac{1}{f_1} + \frac{1}{f_2} \left(\because P = \frac{1}{f}\right)$$

(ii) Given: Wavelength of light $(\lambda) = 550$ nm
$= 550 \times 10^{-9}$ m
Slit separation $(d) = 1.1 \times 10^{-3}$ m
Distance of screen $(D) = 2.2$ m
Slit width $(a) = 1.2 \times 10^{-6}$ m

(I) Fringe Width $(\beta) = \frac{\lambda D}{d}$

$$= \frac{550 \times 10^{-9} \times 2.2}{1.1 \times 10^{-3}}$$

$$= \frac{1210.0 \times 10^{-9}}{1.1 \times 10^{-3}}$$

$$= \frac{1.21 \times 10^{-6}}{1.1 \times 10^{-3}}$$

$= 1.1 \times 10^{-3}$ m
$= 1.1$ nm

(II) Position of nth dark fringe (yn) $= \frac{2n-1}{2}\beta$

For the second dark fringe (n = 2).

$= \frac{(2 \times 2 - 1)}{2}\beta$

$= \frac{(4-1)}{2}\beta$

$= \frac{3}{2}\beta$

$= 1.5 \times 1.1$

$= 1.65$ nm

(III) When immersed in water, the speed of light decreases, which reduces the wavelength:

$\lambda_{\text{water}} = \frac{\lambda_{\text{air}}}{\mu}$ ... (where $\mu \approx 1.33$ for water)

Since fringe width (β) is directly proportional to wavelength, the fringe width decreases.

Thus, the new fringe width:

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

$= \frac{1.1}{1.33}$

$= 0.827$ nm

67. (a) • Formula: Resistance is given by $R = \rho\frac{l}{A}$.

• Individual Wires:

• $R_1 = \rho_1\frac{l}{A}$

• $R_2 = \rho_2\frac{l}{A}$

• Series Combination: Total resistance $R_{cq} = R_1 + R_2 = (\rho_1 + \rho_2)\frac{l}{A}$.

• Equivalent Formula: For the combination, total length is $2l$ and area is A :

$R_{cq} = \rho_{cq}\frac{2l}{A}$

• Calculation:

$\rho_{cq}\frac{2l}{A} = (\rho_1 + \rho_2)\frac{l}{A} \Longrightarrow \rho_{cq} = \frac{1}{2}(\rho_1 + \rho_2)$

68. (c)• Formula: The radius of a circular path in a magnetic field is $r = \frac{mv}{qB}$.

• Given: Velocity (v) and magnetic field (B) are identical for both, meaning $r \propto \frac{m}{q}$.

• Observation: The diagram shows that the circular path of particle 2 has a larger curvature radius than particle $1 (r_2 > r_1)$.

• Calculation:

$\frac{m_2}{q_2} > \frac{m_1}{q_1} \Longrightarrow \frac{m_1}{m_2} < \frac{q_1}{q_2}$

69. (b) • Formula: Current is charge divided by time period, $I = \frac{q}{T}$.

Given:

Charge $q = e$

Frequency (revolutions per second) $n = \frac{1}{T}$

Calculation:

$I = q \cdot \left(\frac{1}{T}\right) = e \cdot n = ne$

70. (b) • Concept: By Faraday's law, the rate of change of magnetic flux ($\frac{d\phi}{dt}$) equals induced electromotive force (emf/voltage).

Formula: Voltage $V = \frac{\text{Work done}(W}{\text{Charge}(q)}$

Dimensional Analysis:

Work $[W] = [\mathrm{ML}^2\ \mathrm{T}^{-2}]$

Charge $[q]=[\mathrm{AT}]$
Calculation:
$$\left[\frac{d\phi}{dt}\right]=\frac{[\mathrm{M\ L^2\ T^{-2}}]}{[\mathrm{A\ T}]}=[\mathrm{M\ L^2\ T^{-3}\ A^{-1}}]$$

71. **(d)** Moving conductor 1 in a magnetic field induces an EMF (Motional EMF).
This EMF creates a current in the closed loop formed by the rails and conductor 2.
The induced current in conductor 2, which is in a magnetic field, experiences a magnetic force (Lorentz force).
Direction of induced current in conductor 1: $\dot{\mathrm{v}}\times\dot{\mathrm{B}}$
Force on conductor 2: $\dot{\mathrm{F}}=\mathrm{I}(\mathrm{i}\times\dot{\mathrm{B}})$
Lenz's Law: The system will try to oppose the change in flux.
Let $\hat{\imath}$ be right, $\hat{\jmath}$ be up, and $\hat{\mathrm{k}}$ be out of the page.
The magnetic field $\vec{\mathrm{B}}$ is into the page, so $\vec{\mathrm{B}}=-\mathrm{B}\hat{\mathrm{k}}$.
Conductor 1 moves right, so $\vec{\mathrm{v}}=\mathrm{vi}$.
Induced current direction in 1 is $\dot{\mathrm{v}}\times\dot{\mathrm{B}}=(\mathrm{v}\hat{\imath})\times(-\mathrm{B}\hat{\mathrm{k}})$
$=\mathrm{vB}(\hat{\imath}\times-\hat{\mathrm{k}})$
$=\mathrm{vB}(\hat{\jmath})$
So current flows "up" in conductor 1. In the closed loop, this means current flows "down" through conductor 2.
For conductor 2 , the length vector $\vec{\mathrm{l}}$ is along $-\hat{\jmath}$.
Magnetic force on conductor 2: $\dot{\mathrm{F}}=\mathrm{I}\dot{\mathrm{l}}\times\dot{\mathrm{B}}$
$=\mathrm{I}(-\mathrm{L}\hat{\jmath})\times(-\mathrm{B}\hat{\mathrm{k}})$
$=\mathrm{ILB}(\hat{\jmath}\times\hat{\mathrm{k}})$
$=\mathrm{ILB}\hat{\imath}$

72. **(c)** • Alternating Current (AC)
The given voltage function is:
$v=14\sin(314t)\mathrm{V}\implies V_0=14\ \mathrm{V}$
(1) Average Value (V_{avg}): Over one full cycle, a symmetric sine wave spends equal time in positive and negative phases.
$V_{\mathrm{avg}}=0\ \mathrm{V}$
(2) Effective (RMS) Value (V_{rms}):
$$V_{\mathrm{rms}}=\frac{V_0}{\sqrt{2}}=\frac{14}{1.414}\approx 9.9\ \mathrm{V}\approx 10\ \mathrm{V}$$

73. **(b)** • Electromagnetic Waves
(1) Fundamental Relation: The ratio of the electric field amplitude (E_0) to the magnetic field amplitude (B_0) equals the speed of the wave (v) in that medium:
$$\frac{E_0}{B_0}=v$$
(2) Speed in Medium: Given the refractive index of glass is $n=1.5$:
$$v=\frac{c}{n}=\frac{3\times10^8\ \mathrm{ms^{-1}}}{1.5}=2\times10^8\ \mathrm{ms^{-1}}$$

74. **(b)** • Photoelectric Effect
(1) Photon Energy Equation: Energy is inversely proportional to wavelength:
$$E=\frac{hc}{\lambda}$$
(2) Wavelength Change: Since the wavelength decreases ($600\ \mathrm{nm}\rightarrow 400\ \mathrm{nm}$), the individual photon energy (E) increases.
(3) Einstein's Photoelectric Equation:
$eV_0=E-\phi$
Because the work function (ϕ) remains constant, an increase in photon energy (E) directly results in an increase in the stopping/cut-off potential (V_0).

75. **(b)** • Photoelectric Threshold
(1) Calculate Incident Photon Energy (E):

$$E=\frac{hc}{\lambda}=\frac{1240\mathrm{eV}\cdot\ \mathrm{nm}}{331\ \mathrm{nm}}\approx 3.75\mathrm{eV}$$

(2) Condition for Photoelectric Emission:
Photoelectric emission occurs only if the energy of the incident photon is greater than or equal to the work function of the metal ($E\geq\phi$).
(3) Comparing with given metals:
$\mathrm{Na}(1.92\mathrm{eV}): 3.75>1.92 \Longrightarrow$ Emission occurs
$\mathrm{K}(2.15\mathrm{eV}): 3.75>2.15 \Longrightarrow$ Emission occurs
$\mathrm{Ca}(3.20\mathrm{eV}): 3.75>3.20 \Longrightarrow$ Emission occurs
$\mathrm{Mo}(4.17\mathrm{eV}): 3.75<4.17 \Longrightarrow$ No emission
Therefore, only Molybdenum (Mo) fails to exhibit emission.

76. (d) • de Broglie Wavelength
Step-by-Step Analysis
(1) Formula: The relationship between de Broglie wavelength (λ) and kinetic energy (K) is:

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

(2) New Wavelength Calculation: When kinetic energy becomes four times ($K'=4K$) :

$$\lambda'=\frac{h}{\sqrt{2m(4K)}}=\frac{1}{2}\left(\frac{h}{\sqrt{2mK}}\right)=0.5\lambda$$

(3) Percentage Change:

$$\Delta\lambda\%=\frac{\lambda'-\lambda}{\lambda}\times 100\%=\frac{0.5\lambda-\lambda}{\lambda}\times 100\%=-50\%$$

77. (a) • Paschen Series
Hydrogen spectral series:
• Lyman → Ultraviolet
• Balmer → Visible
• Paschen - Infrared
• Brackett - Infrared

78. (c) Reverse-Biased p-n Junction
• In reverse bias, depletion layer becomes wider and has very high resistance.
Hence almost the entire applied voltage drops across the depletion region.

79. (a) Assertion (A): True
• In a complete circuit, the algebraic sum of potential changes around a closed loop is zero (Kirchhoff's loop rule).
Reason (R): True
• After one complete round, the charge returns to the same point, so the net change in electric potential is zero.
The reason correctly explains the assertion.

80. (c) Assertion (A): True
A ferromagnetic substance becomes paramagnetic when heated above its Curie temperature.
Reason (R): False
Magnetization decreases gradually with temperature and becomes zero at the Curie point; it does not disappear abruptly.

81. (d) Assertion (A): False
For a convex glass lens immersed in water,

$$P=\left(\frac{n_{\text{glass}}}{n_{\text{water}}}-1\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

Since $\frac{n_{\text{glas}}}{n_{\text{kalk}}}-1$ decreases, the power decreases (not increases).
Reason (R): False
Focal length depends on both refractive indices and radii of curvature, not only on radii.

82. (a) Assertion (A): True
For equal carrier concentration, n-type semiconductors generally have higher conductivity because electrons have greater mobility than holes.
Reason (R): True
Electrons in the conduction band are more mobile than holes in the valence band.

The reason correctly explains the assertion.

83. Given Data:

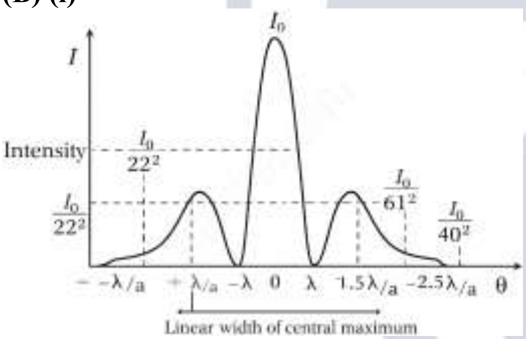
• Charge magnitude (q): $1\mu\text{C} = 1 \times 10^{-6}\text{C}$
• Separation distance ($2a$): $10 \text{ cm} = 0.1 \text{ m}$
• Electric field (E): 100 N/C

(1) Calculate the Electric Dipole Moment (p):
$p = q \times 2a = (1 \times 10^{-6}\text{C}) \times 0.1 \text{ m} = 1 \times 10^{-7}\text{C} \cdot \text{ m}$
(2) Work Done Formula:
The work done in rotating a dipole from an angle θ_1 to θ_2 is:
$W = pE(\cos\theta_1 - \cos\theta_2)$
(3) Substitute Angles:
(4) Stable equilibrium: $\theta_1 = 0°$
(5) Unstable equilibrium: $\theta_2 = 180°$
$W = pE(\cos 0° - \cos 180°) = pE(1 - (-1)) = 2pE$
(6) Calculate Final Work Done:
$W = 2 \times (1 \times 10^{-7}\text{C} \cdot \text{ m}) \times 100 \text{ N/C} = 2 \times 10^{-5} \text{ J}$

84. (A) • Huygens Principle:

(1) Each point on a primary wavefront acts as a source of secondary spherical wavefronts (wavelets) that spread out in all directions with the speed of light.
(2) The forward envelope (tangential surface) touching these secondary wavelets at any later time gives the new position of the wavefront.
• Justification for Absence of Backwave:
The amplitude of secondary wavelets in a given direction is proportional to the obliquity factor $\frac{1}{2}(1 + \cos\theta)$, where θ is the angle with the forward direction of propagation. For the backward direction, $\theta = 180°$, so $\cos 180° = -1$. The factor becomes zero, preventing the formation of a backwave.

(B) (i)



The graph of intensity (I) versus angular position (θ) or $\sin\theta$ shows:
(1) A central peak at $\theta = 0$ with maximum intensity I_0.
(2) First minima occurring at $\sin\theta = \pm\frac{\lambda}{a}$
(3) Secondary maxima occurring roughly at $\sin\theta = \pm\frac{1.5\lambda}{a}, \pm\frac{2.5\lambda}{a}$ etc., with rapidly decreasing intensity.
The intensity of the central maximum is much higher than the secondary ones (roughly in the ratio $1:\frac{1}{22}:\frac{1}{61}$).
(ii) Linear Width of Central Maximum:
The linear width of the central maximum (W) is defined as the distance between the first minima on either side of the center.
The angular position of the first minimum is $\theta \approx \frac{\lambda}{a}$.
The linear distance from the center to the first minimum is $y = D\tan\theta$
$\approx \frac{\lambda}{a}$
Total linear width (W) = 2y
$= \frac{2D\lambda}{a}$
From the formula,
$W = \frac{2D\lambda}{a}$

We see that W ∝ D.
Therefore, if the separation between the slit and the screen (D) is decreased, the linear width of the central maximum will decrease.

85. Given: Depth (h) = 1 m

Refractive index $(\mu) = \sqrt{2}$

Critical angle (C) $= \frac{1}{\mu}$

$= \frac{1}{\sqrt{2}}$

$= 45^{\circ}$

Radius of the circle (r) = htanC

$= 1\text{ m} \times \tan 45^{\circ}$

$= 1\text{ m} \times 1$

$= 1\text{ m}$

Area(A) $= \pi r^2$

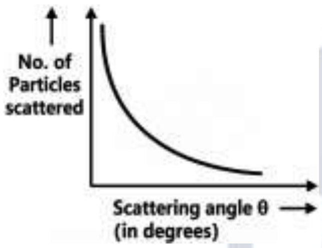
$= \pi \times (1)^2$

$= \pi m^2$

$\approx 3.14159\text{ m}^2$

∴ The area of the surface through which light emerges is πm^2.

86.



The graph plots the number of scattered α-particles (N) on the Y-axis (often on a log scale) against the scattering angle (θ) on the X-axis.
The graph shows a very high count for small angles $(\theta < 1^{\circ})$ and drops exponentially as θ increases, with very few particles scattered at angles near 180°.
Two conclusions from the graph:
(1) Most of the atom is empty space: It is implied that the majority of the atom's volume is empty because the great majority of α particles passed through the gold foil with little to no deflection (small θ).
(2) The nucleus is small and positively charged: The percentage of α-particles that were deflected by more than 90° was quite small, approximately 1 in 8000 . This suggests that an incredibly tiny, compact area known as the nucleus contains the atom's positive charge and almost all of its mass.

87. Given: Intrinsic carrier concentration $(n_1) = 5 \times 10^8\text{ m}^{-3}$ ... [since intrinsic $n_h = n_i$]

New electron concentration after doping $(n_e) = 4 \times 10^{12}\text{ m}^{-3}$

New hole concentration $(n_h) = \frac{n_i^2}{n_e}$

$= \frac{(5 \times 10^8)^2}{4 \times 10^{12}}$

$= \frac{25 \times 10^{16}}{4 \times 10^{12}}$

$= 6.25 \times 10^{16-12}$

$= 6.25 \times 10^4\text{ m}^{-3}$

Comparing the concentrations:

$n_e = 4 \times 10^{12}\text{ m}^{-3}$

$n_h = 6.25 \times 10^4\text{ m}^{-3}$

Since $n_e > n_h$, electrons are the majority charge carriers. Therefore, the semiconductor is an n-type semiconductor.

∴ The new hole concentration is $6.25 \times 10^4\text{ m}^{-3}$ and the semiconductor formed is n-type.

88. (1) Kirchhoff's Rules

• Kirchhoff's First Rule (Junction Rule): The total current entering a junction equals the total current leaving it ($\sum I = 0$). It is based on the conservation of charge.
• Kirchhoff's Second Rule (Loop Rule): The algebraic sum of changes in potential around any closed loop is zero ($\sum \Delta V = 0$). It is based on the conservation of energy.
(2) Finding Current in Branch FC
Let's assign currents to the loops:
• Let I_1 be the current flowing clockwise in the upper loop $ABCF$.
• Let I_2 be the current flowing counter-clockwise in the lower loop $FCDE$.
• By junction rule at F, the current flowing from F to C in the central branch is $I_{FC} = I_1 - I_2$.
Apply Loop Rule to Upper Loop ABCF (moving clockwise starting from F):
$+5\text{ V} - I_1(1\Omega) - 3\text{ V} - I_1(3\Omega) - (I_1 - I_2)(1\Omega) - 2\text{ V} = 0$
$5 - I_1 - 3 - 3I_1 - I_1 + I_2 - 2 = 0$
$-5I_1 + I_2 = 0 \Longrightarrow I_2 = 5I_1$ ....(i)
Apply Loop Rule to Lower Loop FCDE (moving counter-clockwise starting from E):
$-I_2(4\Omega) - (I_2 - I_1)(1\Omega) + 2\text{ V} = 0$
$-4I_2 - I_2 + I_1 + 2 = 0$
$I_1 - 5I_2 = -2$ ....(ii)
Substitute Equation 1 into Equation 2:
$I_1 - 5(5I_1) = -2$
$$I_1 - 25I_1 = -2 \Longrightarrow -24I_1 = -2 \Longrightarrow I_1 = \frac{1}{12}\text{ A}$$
Find I_2 :
$$I_2 = 5\left(\frac{1}{12}\right) = \frac{5}{12}\text{ A}$$
Calculate current through branch FC (I_{PC}):
$$I_{FC} = I_1 - I_2 = \frac{1}{12} - \frac{5}{12} = -\frac{4}{12} = -\frac{1}{3}\text{ A}$$
• Magnitude: $\frac{1}{3}$ A (or 0.33 A)
• Direction: Since the sign is negative, the current actually flows from C to F.

89. (A) (i) Net magnetic field at a point on conductor 1
The magnetic field due to a long straight wire carrying current I at a distance r is given by $B = \frac{\mu_0 I}{2\pi r}$.
Using the right-hand rule, we find the directions of the fields at conductor 1 along the z -axis:
• Field due to conductor $2(B_2)$: Distance is d, current is I (to the right). The field points out of the page $(+\hat{k})$.
$$B_2 = \frac{\mu_0 I}{2\pi d}\hat{k}$$
• Field due to conductor $3(B_3)$: Distance is $2d$, current is $3I$ (to the left). The field points into the page $(-\hat{k})$.
$$B_3 = \frac{\mu_0(3I)}{2\pi(2d)}(-\hat{k}) = -\frac{3\mu_0 I}{4\pi d}\hat{k}$$
Net Magnetic Field (B_{net}):
$$B_{\text{nct}} = B_2 + B_3 = \frac{\mu_0 I}{2\pi d}\hat{k} - \frac{3\mu_0 I}{4\pi d}\hat{k} = -\frac{\mu_0 I}{4\pi d}\hat{k}$$
• Magnitude: $\frac{\mu_0 I}{4\pi d}$
• Direction: Into the page ($-\hat{k}$ direction).
(ii) Net magnetic force acting on unit length of conductor 1
The magnetic force per unit length is given by $f = I_1 B_{\text{nct}}$.
$$f = (2I) \times \left(\frac{\mu_0 I}{4\pi d}\right) = \frac{\mu_0 I^2}{2\pi d}$$
• Direction: Parallel currents attract, opposite currents repel. Conductor 2 attracts conductor 1 (downward, $-\hat{j}$). Conductor 3 repels conductor 1 (upward, $+\hat{j}$).
• Net Force Direction: Since the field from 3 dominates the net field direction into the page, applying $\vec{F} = I(\vec{L} \times \vec{B})$ where current is along $+\hat{\imath}$ and $\vec{B}$ is along $-\hat{k}$ gives $\hat{\imath} \times (-\hat{k}) = +\hat{j}$ (upward).
• Magnitude: $\frac{\mu_0 I^2}{2xd}$

• Direction: Upward ($+\hat{j}$ direction).

OR

(B)(i) Expression for the induced emf

• Area of the loop: $A = l \times b$

• Magnetic field: $B = B_0 \sin\omega t$

• Magnetic flux (ϕ): $\phi = B \cdot A = B_0 / b \sin\omega t$

By Faraday's Law of Induction, the induced emf (e) is:

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}(B_0 l b \sin\omega t)$$

$$e = -B_0 I b\omega \cos\omega t$$

(ii) Effective value of current (I_{rms})

The peak value of induced emf is $e_0 = B_0 l b\omega$.

The peak value of current is $I_0 = \frac{c_0}{R} = \frac{R_0/h_\omega}{R}$.

The effective (rms) value of current is:

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}} = \frac{B_0 l b\omega}{\sqrt{2}R}$$

90. **(A)** Direction and Duration:

As the loop moves out to the right, the area inside the magnetic field decreases. Thus, the magnetic flux (directed downwards) decreases.

The generated current must provide a downward (within the loop) magnetic field to counteract this drop. The current must flow clockwise according to the right-hand rule (M → N → O → P).

The side of the square (a) is 25 cm .

The current persists as long as the loop is exiting the field.

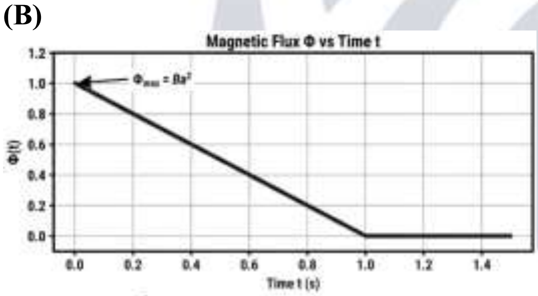
Time taken for the loop to completely exit:

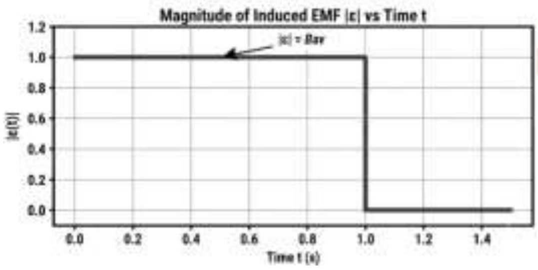
$$\text{t} = \frac{\text{Length of side}}{\text{Velocity}}$$

$$= \frac{25 \text{ cm}}{25 \text{ cm/s}}$$

$$= 1 \text{ s}$$

(B)





91. Infrared (IR) waves are electromagnetic waves with wavelengths longer than visible light but shorter than microwaves. Infrared waves have wavelengths typically between 700 nm and 1 mm . They are produced by hot bodies and molecules.

• Infrared waves are referred to as 'heat waves' due to their efficient absorption by water molecules and other polar molecules found in various materials. The absorption elevates the thermal motion (internal energy) of the molecules, therefore raising the material's temperature.

• For therapeutic purposes and long distance photography.

(1) TV Remote Controls: IR LEDs are used to transmit encoded signals to electronic devices.

(2) Physical Therapy: IR lamps are used to treat muscular strains and provide warmth to tissues.

(3) Night Vision: IR sensors are used in goggles and cameras to detect heat signatures in the dark.

92. **(A)** The de Broglie relation proposed that matter, like radiation, exhibits both particle-like and wave-like properties.

The de Broglie relation is given by:

$$\lambda=\frac{h}{p}$$

$$=\frac{h}{mv}$$

Here:

Wavelength (λ) is a characteristic property of waves (e.g., interference, diffraction).

Momentum (p) is a characteristic property of particles (mass and velocity).

Planck's constant (h) acts as the bridge connecting these two aspects.

The relation shows that a moving particle of momentum p has an associated wave of wavelength λ. This directly links the wave and particle nature of matter in a single equation.

∴ The dual nature is evident because the equation relates a wave parameter (λ) to a particle parameter (p).

(B) The incident photon transfers its energy to the electron. The kinetic energy of the emitted photoelectron determines its de Broglie wavelength.

Since the work function Φ is negligible ($\Phi \approx 0$):

The maximum kinetic energy of the emitted electron is equal to the energy of the incident photon:

$$\mathrm{K}=\frac{hc}{\lambda}$$

Now, substituting this value of kinetic energy into the de Broglie wavelength formula:

$$\lambda_{\mathrm{e}}=\frac{h}{\sqrt{2mK}}$$

$$=\frac{h}{\sqrt{2m\left(\frac{hc}{\lambda}\right)}}$$

$$=\frac{h\cdot\sqrt{\lambda}}{\sqrt{2mhc}}$$

$$=\sqrt{\frac{h^2\lambda}{2mhc}}$$

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

∴ The de Broglie wavelength of the emitted electrons is $\sqrt{\frac{h\lambda}{2mc}}$.

93. In a nuclear reaction, mass number (A) and atomic number (Z) are conserved.

The energy released (Q-value) is due to the mass defect (Δm) converted into energy using:

$$\mathrm{E}=\Delta\mathrm{m}\cdot\mathrm{c}^2$$

Conservation of A:

$$\sum A_{\text{reactants}}=\sum A_{\text{products}}$$

Mass defect Δm :

$$\sum m_{\text{eactans}}-\sum m_{\text{products}}$$

$$\mathrm{Q}=\Delta\mathrm{m(inu)}\times 931.5\mathrm{MeV/u}$$

(A) Value of A :

Conservation of mass number:

$2+2=A+1$

$\Rightarrow A=3$

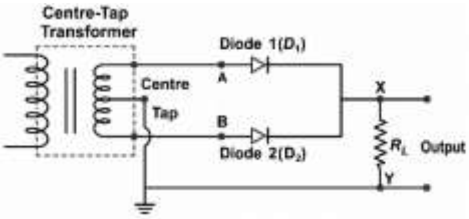
Conservation of atomic number:

$1+1=Z+0$

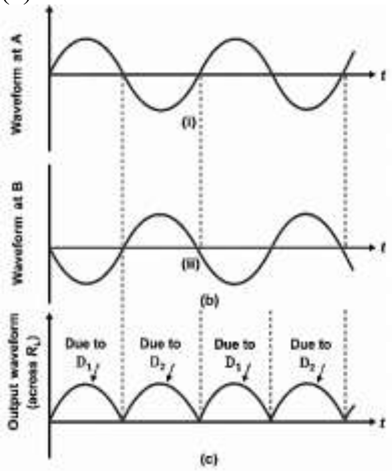
$\Rightarrow Z=2$

Thus, the product X is Helium-3 ($^{3}_{2}He$).
(B) Energy Released:
Total mass of reactants $(M_R) = 2 \times 2.014102$
$= 4.028204u$
Total mass of products $(Mp) = 3.016049 + 1.008665$
$= 4.024714u$
Mass defect $(\Delta m) = M_R - M_p$
$= 4.028204 - 4.024714$
$= 0.00349u$
Energy released $(Q) = 0.00349 \times 931.5$
$\approx 3.2509MeV$

94.



(a) A Full-wave rectifier circuit



Input and output waveforms

• The circuit using two diodes, shown in Fig. (a), gives an output rectified voltage corresponding to both the positive as well as negative half of the ac cycle. Hence, it is known as a full-wave rectifier.
Here, the p -side of the two diodes is connected to the ends of the secondary of the transformer. The n -side of the diodes is connected together, and the output is taken between the common point of the diodes and the midpoint of the secondary transformer. So, for a fullwave rectifier, the secondary of the transformer is provided with a centre tapping, and so it is called a centre-tap transformer.
As can be seen from Fig. (c), the voltage rectified by each diode is only half the total secondary voltage. Each diode rectifies only for half the cycle, but the two do so for alternate cycles. Thus, the output between their common terminals and the centre tap of the transformer becomes a full-wave rectifier output.
Suppose the input voltage to A with respect to the centre tap at any instant is positive. It is clear that, at that instant, the voltage at B being out of phase will be negative as shown in Fig. (b). So, diode D_1 gets forward-biased and conducts (while D_2, being reverse-biased, is not conducting). Hence, during this positive half cycle, we get an output current (and an output voltage across the load resistor R_L) as shown in Fig. (c).
In the course of the AC cycle, when the voltage at A becomes negative with respect to the centre tap, the voltage at B would be positive. In this part of the cycle, diode D_1 would not conduct, but diode D_2 would, giving an output current and output voltage (across R_L) during the negative half cycle of the input ac. Thus, we get output voltage during both the positive and the negative half of the cycle.

95. (i) (d) Even if the circuit is not turned off, manganin's resistance (R) stays constant because of its very low temperature coefficient of resistance (i.e., even if there is small heating due to the Joule effect).
Because R is constant, the ratio $\frac{V}{I}$ remains constant.
A constant ratio results in a linear graph (straight line) passing through the origin in the V-I plane.

∴ The graph will be a straight line passing through the origin.

(ii) (c) Both the voltage V, as determined by the voltmeter, and the current I, as determined by the ammeter, determine the computed value of X . Any inaccuracy (systematic or random error) in either instrument will contribute to the total error in X . Based to the rules of error propagation, the total error in the result is the sum of the fractional or percentage errors of the divided numbers. The total error is the sum of the errors in both measurements.

(iii) (b) In the given circuit, moving the slider towards P decreases the effective length of the rheostat wire included in the circuit.

Since Resistance R ∝ Length, the rheostat resistance R_{thenstat} decreases.

As R_{total} decreases, the current I in the circuit increases $\left(I=\frac{E}{R_{\text{total}}}\right)$. Thus, the ammeter reading increases.

The voltmeter is connected across the fixed resistor X . The potential drop across it is V = IX. Since I has increased and X is constant, the potential drop V also increases. Thus, the voltmeter reading increases. Thus, readings in both the voltmeter and the ammeter increase.

(iv) (A) (b) The three parts of the wire are connected in series, so the same current I flows through each part. The material is the same, so the number density of free electrons (n) is the same.

Thus, $v_d \propto \frac{1}{A} \propto \frac{1}{R^2}$

Let's calculate the ratios:

Part $AC: R_1=r \Rightarrow v_1 \propto \frac{1}{r^2}$

Part CD: $R_2=\frac{r}{3} \Rightarrow v_2 \propto \frac{1}{(r/3)^2}=\frac{9}{r^2}$

Part DB: $R_3=\frac{r}{2} \Rightarrow v_3 \propto \frac{1}{(r/2)^2}=\frac{4}{r^2}$

Comparing the values: $v_2=9v_1$ and $v_3=4v_1$.

Therefore, $v_2>v_3>v_1$.

OR

(B) (c) Since the wires are in series, the current I is constant throughout.

The material is the same, so the resistivity ρ is constant.

Thus, $E \propto \frac{1}{A} \propto \frac{1}{R^2}$.

For part $AC: E_1 \propto \frac{1}{r^2}$

For part CD: $E_2 \propto \frac{1}{(r/3)^2}=\frac{9}{r^2}$

For part DB: $E_3 \propto \frac{1}{(r/2)^2}=\frac{4}{r^2}$

Comparing the magnitudes: $E_2>E_3>E_1$.

96. (i) (b) The objective lens is the lens through which Light from an object at infinity enters the large objective lens. It converges the light to form a diminished, inverted, and real image at its second focal point.

The eyepiece lens intermediate real image is positioned within the focal length of the eyepiece. The eyepiece then forms a highly magnified, inverted (with respect to the original object), and virtual image.

(ii) (d) The focal lengths of the objective (f_0) and eyepiece (f_0) are clearly related to magnification. Because glass's refractive index (and hence the focus length) varies with wavelength, it also depends on the color of light (Chromatic Aberration). The aperture (diameter) of the lenses influences both the light-gathering capacity and the resolving power (the sharpness or brightness of the image); however, it is not included in the mathematical equation for magnification. Thus, magnification is independent of the apertures of the lenses.

(iii) (c) When normal adjustment is used (final picture at infinity), the distance is f_0+f_e. The eyepiece is moved closer to the objective, making the separation $L=f_0+u_e$, where ue is less than fe. This is done so that the final image is made at the shortest distance of distinct vision (D). In this case, $L<f_0+f_e$. In normal use, the distance between them is never more than f_0+f_e -

(iv) (A) (a) An astronomical telescope has objective lens and eyepiece of focal lengths 80 cm and 4 cm respectively. To view the image in normal adjustment, the lenses must be separated by a distance of 4 cm.

Explanation:

Given: Focal length of objective $(f_0)=80$ cm

Focal length of eyepiece $(f_e)=4$ cm

In normal adjustment, the lenses are separated by the sum of their focal lengths:

$L=f_0+f_e$

$=80 \text{ cm}+4 \text{ cm}$

$= 84$ cm

∴ The separation distance is 84 cm .

OR

(B) (d) From the previous part (iv)(A), we have:

Focal length of objective $(f_0) = 80$ cm

Focal length of eyepiece $(f_e) = 4$ cm.

Calculating magnifying power:

$$M = \frac{80}{4}$$

$= 20$

This means the distant object will appear 20 times larger in angular size when viewed through the telescope.

97. (A) (i) The absolute refractive index (n) of a medium is defined as the ratio of the speed of light in vacuum (c) to the speed of light in that medium (v).

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

(ii) At the position of minimum deviation $(\delta = \delta_m)$:

The angle of incidence equals the angle of emergence (i) $= e$

The angle of refraction at the first face equals the angle of incidence at the second face:

$r_1 = r_2 = r$

From $A = r_1 + r_2$, we get:

$A = r + r$

$\Rightarrow A = 2r$

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

From $\delta_m = i + e - A$, we get:

$\delta_m = i + i - A$

$\Rightarrow \delta_m = 2i - A$

$$\Rightarrow i = \frac{A + \delta_m}{2}$$

Applying Snell's Law at the first surface:

$$\mu = \frac{\sin i}{\sin r_1}$$

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

Substituting the values of i and r :

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

(iii) A beam enters the medium undisturbed when it is incident ordinarily $(i = 0°)$. After that, it strikes a different surface, and how it behaves depends on whether the angle of incidence is greater than the critical angle (ic).

Critical angle $(i_c) = \sin^{-1}\left(\frac{1}{\mu}\right)$

If $i > i_c$, total internal reflection (TIR) occurs.

The ray QP is incident normally on BC , so it enters the prism without bending and travels straight.

Assuming the prism is equilateral ($A = 60°$), the ray hitting the side AC will have an angle of incidence (i) = 60°.

$\mu = 1.5$

$$\sin i_c = \frac{1}{1.5}$$

$$= \frac{2}{3}$$

$\sin i_c \approx 0.66$

$i_c \approx 41.8°$

The ray will experience total internal reflection (TIR) at the face because the angle of incidence (i) = 60°, is larger than the critical angle, ic ≈ 41.8°. The rules of reflection will cause it to reflect back into the prism.

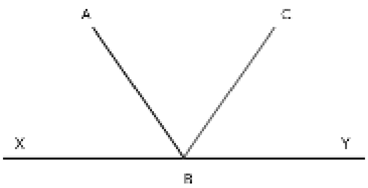
∴ The ray enters undeviated, hits the slanted face at 60°, and undergoes total internal reflection because the angle of incidence exceeds the critical angle.

OR

(B) (i)

	Wavefront	Ray
(i)	A wavefront is a surface that represents points in a medium that are in phase (i.e., oscillating in synchrony) with each other.	A ray is a straight line representing the path along which light travels.
(ii)	It's perpendicular to the direction of propagation of the wave.	It's used to simplify the description of light propagation, particularly in geometric optics.

(ii) Law of Reflection by Huygens' Principle



Let a plane wavefront AB be incident on a reflecting surface XY. Let v be the wave speed.
• Time taken for point B to reach C is t, so $BC = vt$.
• In the same time t, secondary wavelets from A travel a distance vt, forming a reflected wavefront tangent CD where $AD = vt$.
In $\triangle ABC$ and $\triangle ADC$:
• $\angle ABC = \angle ADC = 90^\circ$
• $BC = AD = vt$
• $AC = AC$ (Common side)
By RHS congruence, $\triangle ABC \cong \triangle ADC$. Therefore:
$\angle BAC = \angle DCA \Longrightarrow i = r$ (Law of Reflection verified)
(iii) Refraction of a Plane Wave by a Convex Lens
• The central portion of the incoming plane wavefront passes through the thickest part of the lens and slows down the most.
• The edges pass through the thinner parts and experience less delay.
• As a result, the emerging wavefront tilts inward, becoming a spherical converging wavefront focused at point F.

98. (A) (i) (I) Resonant frequency (f_r) is the frequency of the AC source at which the inductive reactance becomes equal to the capacitive reactance ($X_L = X_C$). At this frequency, the impedance of the series LCR circuit is minimum and equal to the resistance ($Z = R$), resulting in maximum current.

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

(II) It is defined as the ratio of real power to apparent power in an AC circuit. Mathematically, it is the cosine of the phase angle (Φ) between voltage and current.

$$\cos\Phi = \frac{R}{Z}$$

The average power dissipated is $P_{avg} = V_{rms}I_{rms}\cos\Phi$. Power is maximum when $\cos\Phi = 1$ .This happens when the circuit is purely resistive or at resonance.

(ii) Given: $L = \frac{5}{\pi}H$

$C = \frac{50}{\pi}\mu F = \frac{50}{\pi} \times 10^{-6}$ F

$R = 400\Omega$

$V = 140\sin(100\pi t)$

From the voltage equation:

$V_0 = 140$ V and

$\omega = 100\pi \text{rad/s}$

Inductive Reactance $(X_L) = \omega L$

$= 100\pi \times \frac{5}{\pi}$

$= 500\Omega$

Capacitive Reactance $(X_C) = \frac{1}{\omega C}$

$= \frac{1}{100\pi \times \frac{50}{\pi} \times 10^{-6}}$

$= \frac{1}{5000 \times 10^{-6}}$

$= \frac{10^6}{5000}$

$= 200\Omega$

(I) Impedance $(Z) = \sqrt{R^2 + (X_L - X_C)^2}$

$= \sqrt{400^2 + (500 - 200)^2}$

$= \sqrt{400^2 + 300^2}$

$= \sqrt{160000 + 90000}$

$= \sqrt{250000}$

$= 500\Omega$

(II) RMS Current (I_{rms}):

Peak current $(I_0) = \frac{V_0}{Z}$

$= \frac{140}{500}$

$= 0.28$ A

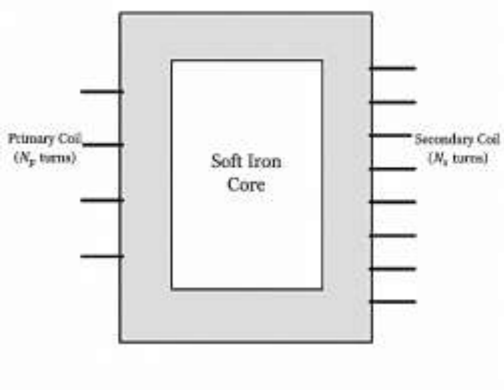
$I_{rms} = \frac{I_0}{\sqrt{2}}$

$= \frac{0.28}{1.4}$

$= 0.2$ A

OR

(B) (i)



• A transformer works on the principle of mutual induction. It changes the voltage levels without changing the frequency.

The output voltage $\left(V_s > V_p\right)$ is raised by a step-up transformer. This is achieved by the secondary coil having more turns than the primary coil$\left(N_s > N_p\right)$.

According to Faraday's law of induction, the emf induced in each turn is the same (assuming perfect flux linkage).

The induced emf in the primary coil is:

$$\varepsilon_p = -N_p \frac{d\phi}{dt}$$

The induced emf in the secondary coil is:

$$\varepsilon_s = -N_s \frac{d\phi}{dt}$$

For an ideal transformer, the terminal voltages V_p and V_s are approximately equal to the emfs. Dividing the two equations:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = k$$

Where k is the transformation ratio. For a step-up transformer, $k > 1$.

(ii) Given: $N_p = 100$,

$N_s = 5000$

$P = 3.3\text{ kW} = 3300\text{ W}$

$V_P = 220\text{ V}$

(I) Current in the Primary Coil $\left(I_p\right)$:

$P = V_p I_p$

$$\Rightarrow I_p = \frac{P}{V_p}$$

$$= \frac{3300}{220}$$

$$= \frac{330}{22}$$

$= 15\text{ A}$

(II) Output Voltage (V_g):

Using the transformer formula:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = V_p \times \frac{N_s}{N_p}$$

$$= 220 \times \frac{5000}{100}$$

$= 220 \times 50$

$= 11000\text{ V}$

$= 11\text{kV}$

99. (A) (i) (I) Work done to move a charge q on an equipotential surface is zero ($W = q\Delta V = 0$). Since $W = \int \vec{E} \cdot \overrightarrow{dl} = Edl\cos\theta$, for W to be zero with non-zero field and displacement, $\cos\theta$ must be zero. Thus $\theta = 90°$, meaning the field is perpendicular to the surface.

(II) A dielectric experiences polarization when exposed to an external field (E_0). An internal "induced" electric field (E_i) is produced in the opposite direction by induced charges on the dielectric's surfaces. $E = E_0 - E_i$, which is less than E_0, is the net field within.

(III) Both the charge Q and the field $E(Q/A\varepsilon_0)$ between the plates of a charged (and isolated) capacitor stay constant. $V = E \times d$ is the potential difference. V likewise reduces proportionately as distance d decreases.

(ii) Given charges are $q_1 = q, q_2 = -4q$, and $q_3 = 2q$.

Distance between any two charges $(r) = a$

Electrostatic Potential Energy $(U) = k \sum \frac{q_i q_j}{r_{ij}}$

$$= k\left[\frac{q_1 q_2}{a} + \frac{q_2 q_3}{a} + \frac{q_3 q_1}{a}\right]$$

$= \frac{k}{a}[(q)(-4q) + (-4q)(2q) + (2q)(q)]$
$= \frac{k}{a}[-4q^2 - 8q^2 + 2q^2]$
$= \frac{k}{a}[-10q^2]$
$= -\frac{10kq^2}{a}$
The work required to dissociate (separate the charges to infinity) is:
$\mathrm{W} = 0 - \mathrm{U}$
$= -\left(-\frac{10kq^2}{4}\right)$
$= \frac{10kq^2}{a}$

OR

(B) (i) (I)
(1) When closing the switch, an electric field is generated throughout the circuit at the velocity of an electromagnetic wave (about 3×10^8 m/s).
(2) This field applies a force on the free electrons located at each location in the wire at that specific moment.
(3) As a result, electrons throughout the whole loop begin to drift simultaneously, irrespective of their proximity to the power source.
(4) Although the slow movement of each electron (drift speed $\sim 10^{-3}$ m/s), the "impulse" propagates to every segment of the circuit nearly immediately.
(II) According to Ohm's law, the relation for the potential is $V = IR$
Voltage (V) is directly proportional to the current (I).
R is the internal resistance of the source.
$\mathrm{I} = \frac{V}{R}$
If V is low, then R must be very low, so that a high current can be drawn from the source.
(III) IR is simply a way to define resistance. According to Ohm's Law, for many materials, as long as physical parameters like temperature don't change, the ratio $\frac{V}{I}$ stays constant (i.e., R is independent of V and I). Not every component (such as transistors and diodes) complies with this.
(ii) Given: $\varepsilon_1 = 12$ V
$r_1 = 1\Omega$
$\varepsilon_2 = 6$ V
$r_2 = 0.5\Omega$
Internal Resistance (r_{eq}) :
$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2}$
$\frac{1}{r_{eq}} = \frac{1}{1} + \frac{1}{0.5}$
$\frac{1}{r_{eq}} = 1 + 2$
$\frac{1}{r_{eq}} = 3$
$r_{eq} = \frac{1}{3}\Omega$
$r_{eq} \approx 0.33\Omega$
Equivalent EMF $(\varepsilon_{eq}) = r_{eq}\left[\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}\right]$
$= \frac{1}{3}\left[\frac{12}{1} + \frac{6}{0.5}\right]$
$= \frac{1}{3}[12 + 12]$

$= \frac{24}{3}$
$= 8\text{ V}$
$\therefore$ The equivalent emf is 8 V , and the internal resistance is $\frac{1}{3}\Omega$.

100. **(b)** When identical conducting spheres are brought into contact, the charge is redistributed equally. The electrostatic force between two charges is given by Coulomb's law:
$F = k\frac{|q_1q_2|}{r^2}$
The initial charges are q and $-2q$, separated by a distance r.
$F = k\frac{|q \cdot (-2q)|}{r^2}$
$= k\frac{2q^2}{r^2}$
Since charges are opposite, the force is attractive.
Total charge $= q + (-2q)$
$= -q$
Since spheres are identical, the charge is distributed equally.
Charge on each sphere $= \frac{-q}{2}$
After separation, the distance becomes $\frac{r}{2}$.
Now both charges are $-\frac{q}{2}$, so the force is repulsive.
$F' = k\frac{\left(\frac{q}{2}\right)^2}{\left(\frac{r}{2}\right)^2}$
$= k\frac{q^2/4}{r^2/4}$
$= k\frac{q^2}{r^2}$
To find the relationship between the new force F' and the initial force F :
$\frac{F'}{F} = \frac{k\frac{q^2}{r^2}}{k\frac{2q^2}{r^2}} = \frac{1}{2}$
Therefore $F' = \frac{F}{2}$
Hence, the force becomes half and is repulsive.

101. **(d)** The electric field is related to electric potential by:
$E = -\frac{dV}{dx}$
Force on a charge:
$F = qE$
Thus, the magnitude of force depends on the slope of the V vs x graph.
A steeper slope has a larger electric field.
Flat region having zero force.
The graph is horizontal (constant potential) at P .
$\frac{dV}{dx} = 0$
The graph has a moderate negative slope at Q . This means a finite electric field and moderate force.
Again, the graph is flat (constant potential) at R .
The graph rises very steeply (large positive slope) at S . Since the electric field magnitude depends on slope.
$|E| = \left|\frac{dV}{dx}\right|$
Thus, the force magnitude is maximum at S .

102. **(c)** Magnetic field due to a long straight current-carrying wire:

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

Distance from centre to each corner:

$r = \frac{a}{\sqrt{2}}$

Thus field due to each wire:

$B_0 = \frac{\mu_0 I}{2\pi r}$

$= \frac{\mu_0 I}{2\pi\left(\frac{a}{\sqrt{2}}\right)}$

$= \frac{\mu_0 I\sqrt{2}}{2\pi a}$

Each magnetic field makes a 45° angle with the diagonals. Effective components add vectorially, giving:

$B_{net} = 2\,B_0$

$= 2 \times \frac{\mu_0 I\sqrt{2}}{2\pi a}$

$= \frac{\mu_0 I\sqrt{2}}{\pi a}$

From vector addition, the resultant is along the diagonal OB .

103. **(d)** Magnetic flux through a loop is given by:

$\Phi = BA\cos\theta$

Where:

$B =$ magnetic field strength

$A =$ area of the loop

$\theta =$ angle between magnetic field and area vector

If the area A changes, the flux changes since:

$\Phi \propto A$

If the magnetic field strength changes:

$\Phi \propto B$

So flux changes.

If the loop is rotated, the angle θ changes. Since:

$\Phi \propto \cos\theta$

Flux also changes.

Magnetic flux depends on all three factors: area, magnetic field, and orientation. Changing any one (or more) of them changes flux.

104. **(d)** AC (Alternating Current) has several practical advantages over DC (Direct Current). Easy voltage transformation using transformers, efficient long-distance transmission, economical generation. However, safety depends on magnitude and conditions, not simply AC vs DC . AC generators are simpler and cheaper compared to DC generators. Transformers work only with AC, allowing efficient voltage stepping up/down. High-voltage AC transmission reduces power loss (I^2R losses). AC can be more dangerous than DC at the same voltage.

105. **(c)** A plane electromagnetic wave is represented as:

$\sin(kx \pm \omega t)$

Where,

$k =$ wave number $= \frac{\omega}{v}$

$\varphi =$ angular frequency

$v =$ speed of wave in medium

From the wave equation:

$\varphi = 1.5 \times 10^{11}\,\text{rad/s}$

Refractive index $(n) = 1.5$

Speed of EM wave in medium:

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

$= \frac{3 \times 10^8}{1.5}$
$= 2 \times 10^8$ m/s
Wave number (k) $= \frac{\omega}{v}$
$= \frac{1.5 \times 10^{11}}{2 \times 10^8}$
$= 0.75 \times 10^3$
$= 7.5 \times 10^2\ m^{-1}$
Comparing with $\sin(\alpha x + \omega t)$, we get:
$\alpha = k$
$= 7.5 \times 10^2\ m^{-1}$

106. **(d)** The energy of a photon is given by Planck's equation:
$E = hv$
$= \frac{hc}{\lambda}$
Where:
h = Planck's constant
v = frequency
λ = wavelength
Thus, a higher frequency gives higher energy, and a shorter wavelength gives higher energy.
In the visible spectrum, red colour gives the longest wavelength and the lowest frequency. The yellow colour gives a shorter wavelength and higher frequency than the red colour. Green colour gives a shorter wavelength and higher frequency than yellow colour. Blue colour gives a shorter wavelength and higher frequency than green colour.
Since energy is inversely proportional to wavelength:
$E \propto \frac{1}{\lambda}$
The colour with the shortest wavelength has the maximum photon energy. Blue light has the highest frequency and hence maximum photon energy.

107. **(b)** Atomic nuclei are classified based on similarities in proton number, neutron number, or mass number.
Nuclides with the same number of neutrons, but different protons, are called isotones.

108. **(a)** Given: A = 125
$R_0 \approx 1.2$fm
The radius of a nucleus is given by the empirical formula:
$R = R_0\, A^{1/3}$
$= 1.2 \times (125)^{1/3}$
$= 1.2 \times 5$
$= 6$fm

109. **(c)** Given: $E = -3.4$eV
In the Bohr model of the hydrogen atom:
Energy of n^{th} orbit $(E_n) = -\frac{13.6}{n^2}$eV
$-3.4 = -\frac{13.6}{n^2}$
$n^2 = \frac{13.6}{3.4}$
$n^2 = 4$
$n = 2$
$L = \frac{nh}{2\pi}$
$= \frac{2h}{2\pi}$
$= \frac{h}{\pi}$

110. **(a)** In forward bias, the depletion layer diminishes, facilitating the movement of charge carriers across the junction, hence resulting in reduced resistance. In reverse bias, the depletion layer expands, blocking the movement of charge carriers and resulting in high resistance. A working diode should clearly exhibit this difference.

111. **(c)**For a sinusoidal alternating voltage:

$V = V_0 \sin\omega t$

RMS value:

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

Average value over a complete cycle:

$V_{avg} = 0$

The RMS value is defined as:

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T V^2 dt}$$

For sine wave:

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

Over one full sine wave cycle, the positive and negative halves exhibit symmetry with respect to the time axis. The positive area above the axis is equal in magnitude to the negative area below it, resulting in their cancellation. Hence, the average value over the complete cycle becomes zero.

$V_{avg} = 0$

Thus, $\left(V_{rms}, V_{avg}\right) = \left(\frac{V_0}{\sqrt{2}}, 0\right)$

112. **(d)** The induced emf produced in a coil does not depend on the total amount of magnetic flux linked with it. According to Faraday's Law of Electromagnetic Induction, the induced emf is directly proportional to the rate of change of magnetic flux over time $\left(e \propto \frac{d\Phi}{dt}\right)$, not the flux itself. This means that even if the magnetic flux is very high, the induced emf will be zero if the flux is not changing. Therefore, the assertion that more flux means more emf is incorrect, and the reason stating they are directly proportional is also incorrect.

113. **(a)** The position of the n^{th} bright fringe is $y_n = \frac{n\lambda D}{d}$

position of the n^{th} dark fringe is $y'_n = (2n-1)\frac{\lambda D}{2d}$

The fringe width (β) is defined as the distance between two consecutive bright fringes:

$$\beta = y_{n+1} - y_n$$
$$= \frac{(n+1)\lambda D}{d} - \frac{n\lambda D}{d}$$
$$= \frac{\lambda D}{d}$$

Similarly, the distance between two consecutive dark fringes:

$$\beta = y'_{n+1} - y'_n$$
$$= \frac{(2n+1)\lambda D}{2d}$$
$$= \frac{\lambda d}{d}$$

Since both expressions give the same value, the fringe widths for bright and dark fringes are equal.

∴ Both Assertion and Reason are true, and the Reason correctly explains why the fringe widths are equal by deriving the common expression for β.

114. **(c)** The assertion is true. Fission of very heavy nuclei and fusion of very light nuclei release energy because the products have higher binding energy per nucleon (net increase in binding energy). The Reason is false. The binding energy per nucleon actually rises from light nuclei up to a peak (around mid-mass like Fe) and then falls for heavier nuclei, so the reasons stated are incorrect.

115. **(a)** Assertion (A) is true. The photoelectric effect is an instantaneous (spontaneous) process, occurring within roughly

Reason (R) is true. Classically, the wave theory predicted that energy would be distributed over the entire wavefront, meaning a single electron would need a long time (hours or days) to accumulate enough energy to escape.

Reason (R) is not the explanation. While (R) highlights a failure of the wave theory, it doesn't explain why the effect is spontaneous. The actual explanation for the spontaneity is the particle (photon) nature of light, where a single photon transfers its entire energy to a single electron in a one-to-one collision.

116. **(A)** Given: $P = 2.2\ \text{kW} = 2200\ \text{W}$,

$V = 220\ \text{V}$

(i) Power (P) $= \frac{V^2}{R}$

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

$= \frac{220^2}{2200}$

$= \frac{48400}{2200}$

$= 22\Omega$

(ii) New power consumed operated at 110 V :

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

$= \frac{110^2}{22}$

$= \frac{12100}{22}$

$= 550\ \text{W}$

Heat produced (H) $=$ Pt

Heat produced in 10 minutes:

$H = P' \times t$

$= 550 \times 10\ \text{min}$

$= 550 \times 600\ \text{s}$

$= 330000\ \text{J}$

$= 3.3 \times 10^5\ \text{J}$

OR

(B) Given: Area (A) $= 1\ \text{mm}^2 = 1 \times 10^{-6}\ \text{m}^2$

Current (I) $= 4.0\ \text{A}$

Potential difference (V) $= 2\ \text{V}$

Length (L) $= 1\ \text{m}$

By using Ohm's law:

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

$= \frac{2}{4.0}$

$= 0.5\Omega$

Resistivity of a material is given by:

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

$= \frac{0.5 \times 1 \times 10^{-6}}{1}$

$= 0.5 \times 10^{-6}$

$= 5 \times 10^{-7}\Omega.\text{m}$

$\therefore$ The resistivity of the material of the wire is $5 \times 10^{-7}\Omega.\text{m}$.

117. Given: Plane of coil initially parallel to magnetic field. So, the angle between the area vector and the field $= 90°$.

Hence, $\Phi = 0$ at $t = 0$.

$\Phi = \omega t + \frac{\pi}{2}$

(A) Magnetic flux through a rotating coil$(\Phi) = BA\cos\theta$

$= BA\cos\left(\omega t + \frac{\pi}{2}\right)$

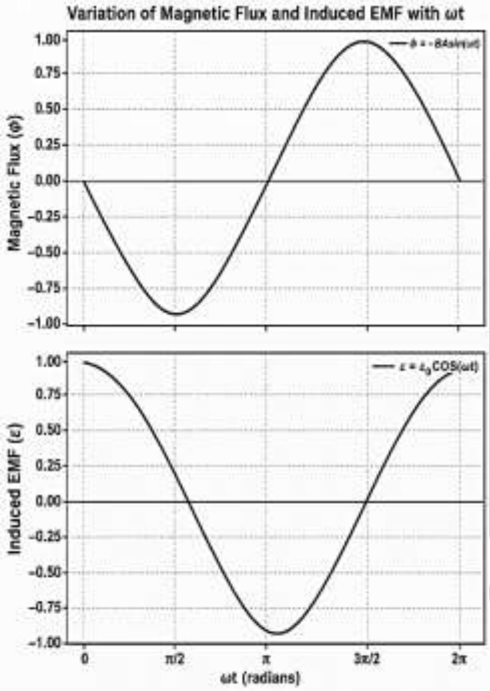
$= BA\sin(\omega t)$

(B) Magnetic flux varies sinusoidally with time, starting from zero. So, Φ vs ωt is a sine curve starting from the origin.

Induced emf $(e) = -\frac{d\phi}{dt}$

$= -BA\omega\cos(\omega t)$

The graph shows a cosine curve, with a maximum at $t = 0$ and a phase difference of 90° with the flux.



118. Given: Real depth $= 12.5$ m

Apparent depth $= 9.0$ m

Speed of light in vacuum $(c) = 3 \times 10^8$ m/s

Refractive index of a medium $(n) = \frac{\text{Real depth}}{\text{Apparent depth}}$

$= \frac{12.5}{9.0}$

$= 1.39$

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

$= \frac{3 \times 10^8}{1.39}$

$\approx 2.16 \times 10^8$ m/s

∴ The speed of light in the liquid is 2.16×10^8 m/s.

119. For thin lenses, the image formed by the first lens acts as the object for the second lens.

Use the lens formula:

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

Let object distance = u, image formed by first lens = v_1.

$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1}$ ....(i)

Since lenses are in contact, the image of the first lens becomes the object for the second lens. So object distance for the second lens = v_1.

Let the final image distance = v

$\frac{1}{v}-\frac{1}{v_1}=\frac{1}{f_2}$ ….(ii)

By adding equations (i) and (ii), we get,

$$\left(\frac{1}{v_1}-\frac{1}{u}\right)+\left(\frac{1}{v}-\frac{1}{v_1}\right)=\frac{1}{f_1}+\frac{1}{f_2}$$

Cancel $\frac{1}{v_1}$:

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f_1}+\frac{1}{f_2}$$

For equivalent single lens:

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

Comparing:

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

Taking reciprocal:

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

120. Arsenic is a pentavalent impurity that produces an n-type semiconductor.

Donor concentration $(N_D)=5\times10^{22}\ m^{-3}$

Since $N_D \gg n_i$:

Majority carriers (electrons): $n_e \approx N_D = 5\times10^{22}\ m^{-3}$

Using the Mass Action Law to find the hole concentration (n_h) :

$$n_h=\frac{n_i^2}{n_e}$$
$$=\frac{(1.5\times10^{16})^2}{5\times10^{22}}$$
$$=\frac{2.25\times10^{32}}{5\times10^{22}}$$
$$=0.45\times10^{10}$$
$$=4.5\times10^{9}\ m^{-3}$$

∴ The majority carrier concentration (electrons) is $5\times10^{22}\ m^{-3}$, and the minority carrier concentration (holes) is $4.5\times10^{9}\ m^{-3}$.

121. Since both capacitors have the same plate area A and plate separation d, their capacitance depends only on the dielectric constant K.

Let the capacitance of X (with air, $K=1$) be $C_X=C$

Let the capacitance of X (with dielectric, $K=4$) be $C_Y=4C$

(A) For two capacitors connected in series, the equivalent capacitance C_{eq} is calculated using the formula:

$$\frac{1}{C_{eq}}=\frac{1}{C_X}+\frac{1}{C_Y}$$

Substituting the given equivalent capacitance (4μ F) and the relationship between C_X and C_Y :

$$\frac{1}{4}=\frac{1}{C}+\frac{1}{4C}$$
$$\frac{1}{4}=\frac{4+1}{4C}$$
$$\frac{1}{4}=\frac{5}{4C}$$
$$4C=5\times4$$
$$4C=20$$
$$C=\frac{20}{4}$$
$$C=5\mu\ F$$

Thus,
$C_X = 5\mu\ F$ ... [From equation (i)]
$C_Y = 4 \times 5$ ... [From equation (ii)]
$C_Y = 20\mu\ F$
(B) In a series combination, the charge Q on each capacitor is the same.
Total charge (Q) $= C_{eq} \times V_{total}$
$= 4\mu\ F \times 6\ V$
$= 24\mu C$
Potential difference across X :
$v_X = \frac{Q}{V_X}$
$= \frac{24}{5}$
$= 4.8\ V$
Potential difference across Y :
$v_Y = \frac{Q}{V_Y}$
$= \frac{24}{20}$
$= 1.2\ V$

122. Given: Length of segment (dl) $= 1\ cm = 10^{-2}\ m$
Current (I) $= 10\ A$
Segment along +x direction (dl) $= 10^{-2}\hat{\imath}$
Field point $= (1,1,0)$
Position vector (r) $= \hat{\imath} + \hat{\jmath}$
$= \sqrt{1^2 + 1^2}$
$= \sqrt{2}$
$dl \times r = (10^{-2}\hat{\imath}) \times (\hat{\imath} + \hat{\jmath})$
Using cross products:
$\hat{\imath} \times \hat{\imath} = 0, \hat{\imath} \times \hat{\jmath} = \hat{k}$
$dl \times I = 10^{-2}\hat{k}$
Magnetic field due to a current element is given by the Biot-Savart law:
$dB = \frac{\mu_0}{4\pi}\frac{Idl \times \hat{r}}{r^2}$
Vector expression (Biot-Savart law):
$dB = \frac{\mu_0}{4\pi}\frac{I(dl \times \tau)}{r^3}$
$= \frac{\mu_0}{4\pi}\frac{I(10^{-2}\hat{k})}{(\sqrt{2})^3}$
$= \frac{10^{-7} \times 10 \times 10^{-2}}{2\sqrt{2}}\hat{k}$
$B = \frac{10^{-8}}{2\sqrt{2}}\hat{k}$
$= \frac{10^{-8}}{2.828}\hat{k}$
$B \approx 3.5 \times 10^{-9}\hat{k}T$

123. Mutual inductance (M) $= \frac{\text{Flux linked with secondary}}{\text{Current in primary}}$
Magnetic field inside a long solenoid (B) $= \mu_0 nI$
$= \mu_0 \frac{N_1}{L} I_1$
The field is uniform inside the solenoid and negligible outside.
The magnetic field exists only inside the solenoid of radius r_1. Area contributing to flux:

$A = \pi r_1^2$
Flux through one turn of the outer coil $(\Phi) = BA$
$= \mu_0 \frac{N_1}{L} I_1 \cdot \pi r_1^2$
Outer coil has N_2 turns:
$\Phi = N_2 \phi$
$= N_2 \mu_0 \frac{N_1}{L} I_1 \pi r_1^2$
Mutual inductance $(M_{12}) = \frac{\phi}{I_1}$
$= \mu_0 \frac{N_1 N_2}{L} \pi r_1^2$
In general $M_{12} = M_{21}$
This is a fundamental property of mutual inductance, independent of geometry (as long as the medium is linear and isotropic).
Thus, $M_{12} = M_{21}$ is valid.

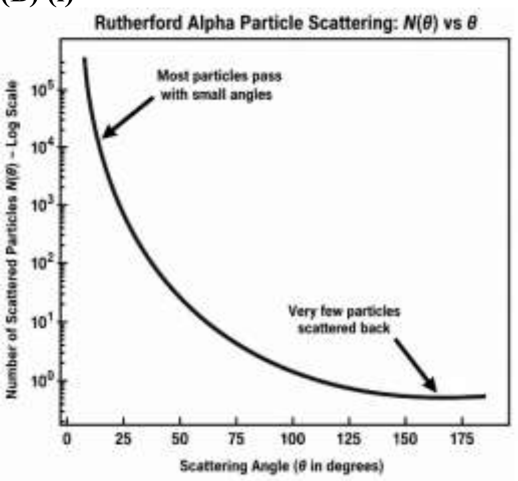
124. Maxwell proposed displacement current to explain the continuity of current in circuits with capacitors. It occurs as a result of a timevarying electric field, even in the absence of physical charge flow.
$i_d = \varepsilon_0 \frac{d\phi_E}{dt}$
Where:
ε_0 = permittivity of free space
Φ_E = electric flux
• Displacement current is defined as:
$i_d = \varepsilon_0 \frac{d\phi_E}{dt}$
Where:
ε_0 = permittivity of free space
Φ_E = electric flux
When a capacitor is charging, conduction current flows in wires; no real charge flows across the dielectric gap, but the electric field between the plates changes with time.
Electric flux between plates $(\Phi_E) = EA$
As the voltage increases, the electric field (Φ_E) changes with time
$E = \frac{V}{d}$
Thus,
$i_d = \varepsilon_0 \frac{d\phi_E}{dt}$
This ensures continuity:
$i_c = i_d$
For a conductor with a constant applied voltage, the electric field is constant, and the electric flux does not change with time.
So, $\frac{d\phi_E}{dt} = 0$
Hence, $i_d = 0$

125. **(A) (i)** (1) Nuclear forces are much stronger then coulomb forces acting between charges or the gravitational forces between masses.
(2) The nuclear force between neutron-neutron, proton-neutron, and proton-proton is approximately the same. The nuclear force does not depend on the electric charge.
(ii) In nuclear reactions, the total number of nucleons (protons + neutrons) is conserved. But total mass is not conserved exactly.
This is explained using Einstein's mass-energy relation:
$E = mc^2$
The mass of a nucleus is less than the sum of the masses of its individual nucleons. This difference is called a mass defect.
$\Delta m = (\text{ sum of individual masses }) - (\text{ actual nuclear mass })$
The missing mass appears as binding energy:

$E_b = \Delta mc^2$
This energy holds nucleons together inside the nucleus.
During nuclear fission or nuclear fusion reactions, products have different binding energies compared to reactants.
If final nuclei have higher binding energy per nucleon, the total mass decreases, and excess mass is released as energy.
In the energy-mass conservation, if the mass decreases, the energy is released, and if the energy is supplied, the mass can be increased.
Thus, even though nucleon number is conserved, a small amount of mass is converted into energy (or vice versa).

OR

(B) (i)



• Conclusions:
(1) An atom is mostly empty space: Since most alpha particles pass through with little or no deflection, positive charge and mass are not uniformly spread, and most of the atom is empty.
(2) Presence of a small, dense nucleus: A very small fraction of particles are deflected through large angles, indicating a strong repulsive force and positive charge is concentrated in a tiny central region (nucleus).

(ii) Bohr's quantization condition $(L) = \frac{nh}{2\pi}$
It is a quantum mechanical effect that becomes significant only at atomic scales.
In atomic systems, masses are extremely small (electron mass), angular momentum is comparable to Planck's constant h, and quantization becomes observable.
In planetary motion, masses are enormous (planet mass), and angular momentum is extremely large.
If we apply Bohr's condition to a planet:
$$n = \frac{2\pi L}{h}$$
Since $L \gg h$, the quantum number n becomes extremely large (of order 10^{70} or more).
For very large quantum numbers, energy levels are extremely closely spaced, and orbits appear continuous rather than discrete. This corresponds to the classical limit (correspondence principle).
The spacing between successive quantized planetary orbits is so tiny that it is impossible to detect experimentally, and motion appears continuous and classical.
Bohr's quantization is valid in principle for planetary motion, but the quantum effects are negligible because Planck's constant is extremely small and planetary angular momentum is extremely large. Hence, planetary orbits appear continuous and not quantized.

126. **(A)** Photoelectric equation $(E) = h\nu$
$= \Phi_0 + K_{max}$
Stopping potential $(K_{max}) = eV_0$
$h = 6.63 \times 10^{-34}$ J.s
$1eV = 1.6 \times 10^{-19}$ J
$E = h\nu$
$= 6.63 \times 10^{-34} \times 6.4 \times 10^{14}$
$= 4.24 \times 10^{-19}$ J
Convert to eV :

$E = \frac{4.24 \times 10^{-19}}{1.6 \times 10^{-19}}$

$= 2.65 eV$

(B) Maximum kinetic energy $(K_{max}) = E - \Phi_0$

$= 2.65 - 1.96$

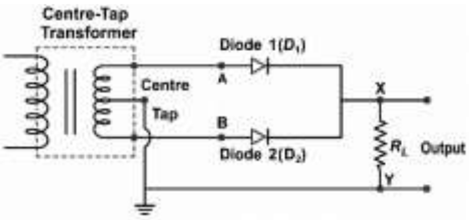
$= 0.69 eV$

(C) Stopping potential $(K_{max}) = eV_0$

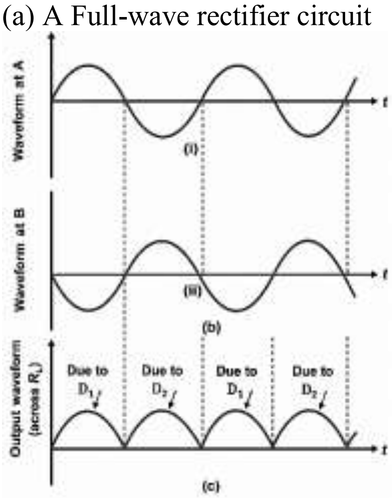
Since kinetic energy is in eV :

$V_0 = 0.69$ V

127.



(a) A Full-wave rectifier circuit



Input and output waveforms

• The circuit using two diodes, shown in Fig. (a), gives an output rectified voltage corresponding to both the positive as well as negative half of the ac cycle. Hence, it is known as a full-wave rectifier.

Here, the p -side of the two diodes is connected to the ends of the secondary of the transformer. The n -side of the diodes is connected together, and the output is taken between the common point of the diodes and the midpoint of the secondary transformer. So, for a fullwave rectifier, the secondary of the transformer is provided with a centre tapping, and so it is called a centre-tap transformer.

As can be seen from Fig. (c), the voltage rectified by each diode is only half the total secondary voltage. Each diode rectifies only for half the cycle, but the two do so for alternate cycles. Thus, the output between their common terminals and the centre tap of the transformer becomes a full-wave rectifier output.

Suppose the input voltage to A with respect to the centre tap at any instant is positive. It is clear that, at that instant, the voltage at B being out of phase will be negative as shown in Fig. (b). So, diode D_1 gets forward-biased and conducts (while D_2, being reverse-biased, is not conducting). Hence, during this positive half cycle, we get an output current (and an output voltage across the load resistor R_L) as shown in Fig. (c).

In the course of the AC cycle, when the voltage at A becomes negative with respect to the centre tap, the voltage at B would be positive. In this part of the cycle, diode D_1 would not conduct, but diode D_2 would, giving an output current and output voltage (across R_L) during the negative half cycle of the input ac. Thus, we get output voltage during both the positive and the negative half of the cycle.

128. **(i) (c)**The electric field points from the higher potential plate to the lower potential plate.

$V = 200$ V

$d = 0.01$ m

For parallel plates $(E) = \frac{V}{d}$

$= \frac{200}{0.01}$

$= 2 \times 10^4\ \text{V/m}$

From the figure, field is along +z direction. Unit vector along z-axis is $\hat{k}$.

$\therefore \dot{E} = 2 \times 10^4 \hat{k}\ \text{V/m}$

(ii) (a) Force on a charge in an electric field $(\vec{F}) = q\vec{E}$

Acceleration $(\dot{a}) = \frac{q\dot{E}}{m}$

For electron:

q = -e

From the previous result:

$\dot{E} = 2 \times 10^4 \hat{k}\ \text{V/m}$

By using electron charge and mass:

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

$m_e = 9.1 \times 10^{-31}\ \text{kg}$

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

$= \frac{1.6 \times 10^{-19} \times 2 \times 10^4}{9.1 \times 10^{-31}}$

$= \frac{3.2 \times 10^{-15}}{9.1 \times 10^{-31}}$

$\approx 3.5 \times 10^{15}\ \text{m s}^{-2}$

An electron has a negative charge, so acceleration is opposite to the field. Field is along $+\hat{k}$ gives acceleration along $-\hat{k}$.

$\therefore \vec{a} = -3.5 \times 10^{15} \hat{k}\ \text{ms}^{-2}$

(iii) (A) (c) Given: Plate length = 0.05 m

$v_x = 3 \times 10^7\ \text{m/s}$

Time of travel $(t) = \frac{\text{distance}}{\text{velocity}}$

$= \frac{0.05}{3 \times 10^7}$

$= \frac{5 \times 10^{-2}}{3 \times 10^7}$

$= 1.67 \times 10^{-9}$

OR

(B) (b) Electron experiences vertical acceleration due to electric field, while horizontal motion is uniform.

$a = 3.5 \times 10^{15}\ \text{m s}^{-2}$

$t = 1.67 \times 10^{-9}\ \text{s}$

Vertical displacement $(y) = \frac{1}{2}at^2$

$= \frac{1}{2} \times 3.5 \times 10^{15} \times (1.67 \times 10^{-9})^2$

$= 0.5 \times 3.5 \times 2.79 \times 10^{-3}$

$\approx 4.9 \times 10^{-3}\ \text{m}$

$\therefore y = 4.9\ \text{mm}$

(iv) (c) An electron enters horizontally with velocity along the x -axis and experiences no force in the horizontal direction, giving uniform motion. Constant vertical acceleration due to the electric field produces projectile-like motion. The motion is similar to uniform velocity in the x direction and uniform acceleration in the vertical direction. Hence, the trajectory is a parabola. From earlier results, the electric field is along $+\hat{k}$, and the electron (negative charge) accelerates opposite. The path should start horizontally and curve downward gradually (parabolic path).

129. **(i) (a)** Interference is a phenomenon that occurs when two or more coherent waves superpose. Constructive interference gives bright fringes.

Destructive interference gives dark fringes. Interference requires the superposition of waves and a phase difference between sources. Such behaviour is a hallmark of wave phenomena.

Young's double-slit experiment was historically important because it provided strong evidence that light behaves as a wave and demonstrated interference fringes.

(ii) (A) (b) Fringe width in Young's double-slit experiment:

$\beta = \frac{\lambda D}{d}$
Where:
$\beta =$ fringe width
$D = 5.0$ m
$d = 2$ mm $= 2 \times 10^{-3}$ m
From the figure:
Successive bright fringes are spaced by 1.5 mm .
$\beta = 1.5$ mm
$= 1.5 \times 10^{-3}$ m
Wavelength $(\lambda) = \frac{\beta d}{D}$
$= \frac{1.5 \times 10^{-3} \times 2 \times 10^{-3}}{5}$
$= 6.0 \times 10^{-7}$ m
$= 600$ nm
The closest option is 590 mm .

OR

(B) (a) Given: $\lambda \approx 590$ nm $= 5.9 \times 10^{-7}$ m
$D = 5.0$ m
$d = 2$ mm $= 2 \times 10^{-3}$ m
Fringe width in Young's double-slit experiment:
$\beta = \frac{\lambda D}{d}$
$= \frac{5.9 \times 10^{-7} \times 5}{2 \times 10^{-3}}$
$= \frac{2.95 \times 10^{-6}}{2 \times 10^{-3}}$
$= 1.475 \times 10^{-3}$ m
≈ 1.5 mm
The closest option is 1.2 mm .
(iii) (c) In Young's double-slit experiment:
$\Delta x = \left(n + \frac{1}{2}\right)\lambda$
For the first minimum:
$\Delta x = \frac{\lambda}{2}$
$\lambda \approx 590$ nm
$= 5.9 \times 10^{-7}$ m
Path difference at minimum $(\Delta x) = \frac{\lambda}{2}$
$= \frac{5.9 \times 10^{-7}}{2}$
$= 2.95 \times 10^{-7}$ m
But point P corresponds to a higher-order minimum (from the diagram). For the third minimum:
$\Delta x = \frac{5\lambda}{2}$
$= \frac{5}{2} \times 5.9 \times 10^{-7}$
$\approx 6.5 \times 10^{-7}$ m
(iv) (d) Fringe width in Young's double-slit experiment:
$\beta = \frac{\lambda D}{d}$
In a medium of refractive index μ :
$\lambda' = \frac{\lambda}{\mu}$
When the experiment is performed in a liquid, the speed of light decreases, and the wavelength decreases.

$\lambda' = \frac{\lambda}{\mu}$ ... $(\mu > 1)$

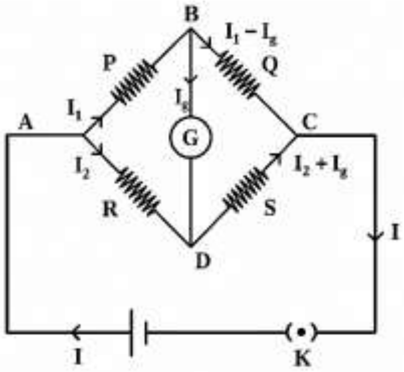
$\beta' = \frac{\lambda' D}{d}$

$= \frac{\lambda}{\mu} \cdot \frac{D}{d}$

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

So fringe width decreases.
A smaller fringe width means fringes come closer together, and the pattern gets compressed.
Hence, the fringe pattern will be compressed.

130. **(A) (i)** The Wheatstone Bridge is shown in the figure:



Applying Kirchhoff's II law to mesh ABDA:
$I_1 P + I_g G - I_2 R = 0$ ...(i)
For the mesh BCDB :
$(I_1 - I_g)Q + [-(I_2 + I_g)S] + [-I_g G] = 0$ ...(ii)
When the bridge is balanced, no current flows through the galvanometer.
i.e., $I_g = 0$ ....(iii)
∴ From equations (i), (ii), and (ii):
$I_1 P = I_2 R$ ...(iv)
$I_1 Q = I_2 S$ ....(v)
From equations (iv) and (v):

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

(ii) From the figure:
Left upper arm $= 20\Omega$
Left lower arm $= 12\Omega$
Right upper arm $= 2\Omega$
Right lower arm $= 1\Omega$
Central branch $= 3\Omega$
Checking bridge balance:

$\frac{20}{12} = 1.67$

$\frac{2}{1} = 2$

$\therefore \frac{20}{12} \neq \frac{2}{1}$

∴ The bridge is not perfectly balanced.
However, the 6 V battery is connected across the left and right nodes.
The bridge can be analyzed by simplifying two parallel series branches:
Upper path resistance:
$20 + 2 = 22\Omega$
Lower path resistance:
$12 + 1 = 13\Omega$

Let total voltage = 6 V
Voltage division in upper branch: Current in upper branch:
$I_u = \frac{6}{22}$
Voltage drop across 20:
$V_A = I_u \times 20$
$= \frac{6 \times 20}{22}$
$= 5.45\ V$
Lower branch current:
$I_1 = \frac{6}{13}$
Voltage at lower junction:
$V_B = I_1 \times 12$
$= \frac{6 \times 12}{13}$
$= 5.54\ V$
Comparing junction potentials:
$V_A \approx 5.45\ V,\ V_B \approx 5.54\ V$
It is almost equal. The potential difference across 3 is negligible.
Potential difference across the central branch is nearly zero, so no current flows through the 3Ω resistor.
∴ The current in the 3Ω branch of a Wheatstone Bridge in the circuit shown in the figure is 0 A .

OR

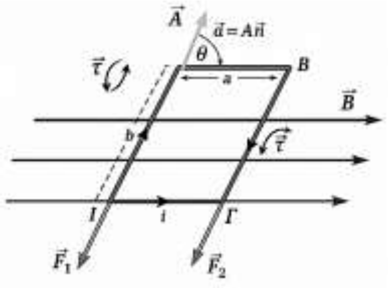
(B) (i) If n = number of free electrons per unit volume, Charge passing per second through area A :
$I = nqAv_d$
Since electron charge magnitude = e,
$I = neAv_d$
Current density (J) $= \frac{I}{A} = neAv_d$
Substitute drift velocity:
$v_d = \frac{eE}{m}\tau$
$J = ne\left(\frac{eE}{m}\tau\right)$
$= \frac{ne^2\tau}{m}E$
Compare with Ohm's law (microscopic form):
$J = \sigma E$
Comparing:
$\sigma = \frac{ne^2\tau}{m}$
Conductivity depends on the number of charge carriers n , relaxation time τ, and the electron charge and mass.
(ii) Given: $R_1 = 1.05\Omega$
$T_1 = 20°C$
$R_2 = 1.38\Omega$
$T_2 = 100°C$
$\Delta T = T_2 - T_1$
$= 100 - 20$
$= 80°C$
Resistance variation with temperature $(R_t) = R_0(1 + \alpha\Delta T)$
$R_2 = R_1(1 + \alpha\Delta T)$
$1.38 = 1.05(1 + 80\alpha)$
$\frac{1.38}{1.05} = 1 + 80\alpha$
$1.314 = 1 + 80\alpha$
$80\alpha = 1.314 - 0.314$
$80\alpha = 0.314$

$\alpha = \dfrac{0.314}{80}$

$= 3.93 \times 10^{-3}\ °C^{-1}$

$\alpha \approx 3.9 \times 10^{-3}\ °C^{-1}$

131. **(A) (i)**



A current-carrying loop in a magnetic field experiences torque due to magnetic forces on its sides.

Magnetic force on a current element:

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

Magnitude of force for side of length a:

$F = IaB\sin\theta$

Torque = force × perpendicular distance between forces

$\tau = F \times b$

$= (IaB\sin\theta)b$

$= IabB\sin\theta$ ... [Since Area of rectangular loop (A) = ab]

$= IAB\sin\theta$

Magnetic dipole moment of loop $(\vec{m}) = I\vec{A}$

So the magnitude of torque $(\tau) = mB\sin\theta$

The direction of torque is perpendicular to both $\vec{m}$ and $\vec{B}$.

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

(ii) Given: Magnetic field (B) = 2.0 T

Current (I) = 5.0 A

Angle $(\theta) = 30°$

$r = \dfrac{10}{\sqrt{\pi}}$ cm

$= \dfrac{10}{\sqrt{\pi}} \times 10^{-2}$ m

$= \dfrac{0.1}{\pi}$ m

Area of circular coil $(A) = \pi r^2$

$= \pi\left(\dfrac{0.1}{\pi}\right)^2$

$= \pi \cdot \dfrac{0.01}{\pi}$

$= 0.01\ m^2$

(I) Magnetic dipole moment (m) = NIA

$= 100 \times 5.0 \times 0.01$

$= 5\ A \cdot m^2$

(II) Torque on coil$(\tau) = mB\sin\theta$

$= 5 \times 2 \times \sin 30°$

$= 10 \times 0.5$

$= 5$ N.m

OR

(B) (i) A current-carrying conductor in a magnetic field experiences a magnetic force due to the motion of charge carriers.

Force on a moving charge $(\vec{f}) = q(\vec{v} \times \vec{B})$

Let:

Number density of electrons $= n$
Drift velocity $= \vec{v}_d$
Volume of conductor $= AL$
Total number of electrons (N) $= nAL$
Force on one electron $(\vec{f}) = -e(\vec{v}_d \times \vec{B})$
Total force on all electron $(\vec{F}) = N\vec{f}$ ....(i)
$= nAL(-e)(\vec{v}_d \times \vec{B})$
$= -neAL(\vec{v}_d \times \vec{B})$
Current (I) $= neAv_d$
$\Rightarrow neA\vec{v}_d = I\vec{l}$
Substitute:
$\vec{F} = -L(\hat{I}l \times \vec{B})$
Force direction is defined using conventional current direction (opposite electron motion). Thus:
$\vec{F} = I(\vec{L} \times \vec{B})$
Magnitude (F) $= ILB\sin\theta$
(ii) From the figure:
Vertical segment length $= 20\text{ cm} = 0.20\text{ m}$
Horizontal displacement $= 50\text{ cm} = 0.50\text{ m}$
Magnetic field $(\vec{B}) = -0.50\hat{k}T$
The wire effectively forms an L-shape.
Net displacement vector $(\vec{L}_{net}) = 0.50\hat{\imath} - 0.20\hat{\jmath}$
Net force $(\vec{F}) = I(\vec{L}_{net} \times \vec{B})$
$= 2[(0.50\hat{\imath} - 0.20\hat{\jmath}) \times (-0.50\hat{k})]$
Cross product:
$\hat{\imath} \times \hat{k} = -\hat{\jmath}$
$\hat{\jmath} \times \hat{k} = \hat{\imath}$
$(0.50\hat{\imath}) \times (-0.50\hat{k}) = 0.25\hat{\jmath}$
$(-0.20\hat{\jmath}) \times (-0.50\hat{k}) = 0.10\hat{\imath}$
So,
$\vec{F} = 2(0.10\hat{\imath} + 0.25\hat{\jmath})$
$= 0.20\hat{\imath} + 0.50\hat{\jmath}$
Magnitude (F) $= \sqrt{0.20^2 + 0.50^2}$
$= \sqrt{0.04 + 0.25}$
$= \sqrt{0.29}$
$F \approx 0.54\text{ N}$

132. **(A) (i) (I)** Consider a slit of width a. If the path difference between light from the top and bottom of the slit is:
$a\sin\theta = n\lambda (n = 1,2,3, \dots)$
Then, the waves cancel pairwise by destructive interference, giving dark fringes.
Thus, the condition for minima:
$a\sin\theta = n\lambda$
Between successive minima, waves interfere constructively to give bright regions. The central maximum occurs at $\theta = 0$, where all wavelets are in phase. Secondary maxima occur between minima due to partial constructive interference.
(II) Higher-order maxima become weaker because:
(1) As angle θ increases, path differences across the slit increase.
(2) Contributions from different parts of the slit increasingly cancel each other.
(3) Only partial constructive interference occurs.
(4) Energy spreads over a wider angular region.
(ii) The two differences between the interference patterns obtained in Young's double slit experiment and the diffraction pattern due to a single slit are as follows:

(1) The fringes in the interference pattern obtained from diffraction are of varying width, while in the case of interference, all are of the same width.
(2) The bright fringes in the interference pattern obtained from diffraction have a central maximum followed by fringes of decreasing intensity, whereas in the case of interference, all the bright fringes are of equal width.

Points	Interference	Diffraction
Origin:	It is produced by the superposition of light from two coherent sources (double slit).	It is produced by the superposition of wavelets from different parts of the same slit (single slit).
Fringe width and intensity:	The fringes are equally spaced and of nearly equal intensity (except due to envelope effects).	The central maximum is widest and brightest, secondary maxima are weaker and not equally spaced. Intensity decreases rapidly for higher orders.

OR

(B) (i) • Construction:
(1) A compound microscope consists of two convex lenses. The lens with the shorter focal length is placed near the object, and is called an 'objective lens' or 'objective piece'.
(2) The lens with a larger focal length and larger aperture placed near the observer's eye is called an 'eye lens' or 'eyepiece'.
(3) Both lenses are fixed in a narrow tube with an adjustable provision.

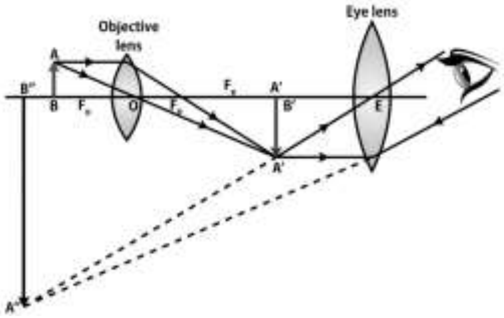
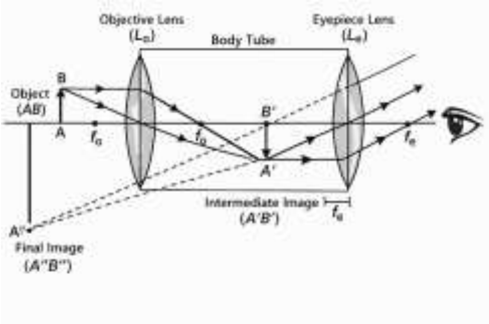


Image formation in a compound microscope

• Working:
(1) The object (AB) is placed at a distance slightly greater than the focal length of the objective lens ($u > f_0$).
(2) A real, inverted, and magnified image ($A'B'$) is formed at the other side of the objective lens.
(3) This image behaves like the object for the eye lens. The position of the eye lens is adjusted in such a way that the image (A^3B^2) falls within the principal focus of the eyepiece.
(4) This eyepiece forms a virtual, enlarged, and erect image (A"B") on the same side of the object.
(5) A compound microscope has 50 to 200 times more magnification power than a simple microscope.
(B) (ii) (I)



When an object is placed between f and 2f of a convex lens, a real, inverted image is formed beyond 2f. The real image is formed due to the actual convergence of light rays.

If the screen is removed, the image still exists at that position in space. A screen is only needed to make the image visible by scattering light to the eye. Without a screen, the image can still be seen by placing the eye at the image location.

Yes, the real image still exists even if the screen is removed, because it is formed by the actual intersection of light rays.

(II) Yes, plane and convex mirrors can produce real images as well. If the object is virtual, i.e., if the light rays converging at a point behind a plane mirror (or a convex mirror) are reflected to a point on a screen placed in front of the mirror, then a real image will be formed.

133. **(c)** Electric Field from Potential

Given:

$V = 10 - 50x$

Electric field:

$E_x = \frac{dV}{dx}$

$\frac{dV}{dx} = -50$

$E_x = -(-50) = 50\ N/C$

Direction is along +x.

134. **(b)** Ratio of Electric Fields on Connected Spheres

When two conducting spheres are connected by a wire,

$V_A = V_B$

$\frac{kQ_A}{r_1} = \frac{kQ_B}{r_2}$

$\frac{Q_A}{Q_B} = \frac{r_1}{r_2}$

Electric field at the surface:

$E = \frac{kQ}{r^2}$

Therefore,

$\frac{E_A}{E_B} = \frac{Q_A/r_1^2}{Q_B/r_2^2} = \frac{Q_A}{Q_B} \cdot \frac{r_2^2}{r_1^2}$

Substituting $\frac{Q_A}{Q_n} = \frac{r_1}{r_2}$,

$\frac{E_A}{E_B} = \frac{r_1}{r_2} \cdot \frac{r_2^2}{r_1^2} = \frac{r_2}{r_1}$

135. **(c)** Magnetic Field Inside a Current-Carrying Wire

For a solid wire with uniform current density.

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

where r is the distance from the axis.

Given:

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

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

136. **(a)** In YDSE, the actual fringe shape is hyperbolic, but when the screen distance $D \gg d$, the fringes becon nearly straight lines.

137. **(c)** Given:

$\varepsilon_r = \frac{3}{2}, \mu_r = \frac{8}{3}$

$n = \sqrt{\mu_r \varepsilon_r} = \sqrt{\frac{8}{3} \times \frac{3}{2}} = \sqrt{4} = 2$

$v = \frac{c}{2}$

Frequency remains unchanged at the boundary.

$\lambda' = \frac{v}{f} = \frac{\lambda}{2}$

• Wavelength is halved and frequency remains unchanged

138. **(b)** Initially:

$V_R = V_L = V_C = 10\ V$

Since $V_L = V_C$, the circuit is at resonance.

$X_L = X_C$

Supply voltage:

$V = V_R = 10\ V$

Let current be I.

$R = \frac{10}{I}, X_L = \frac{10}{I}$

After short-circuiting the capacitor, the circuit becomes RL:

$Z = \sqrt{R^2 + X_L^2} = \sqrt{2}R$

New current:

$I' = \frac{V}{Z} = \frac{10}{\sqrt{2}R} = \frac{I}{\sqrt{2}}$

Voltage across inductor:

$V_L' = I'X_L = \frac{I}{\sqrt{2}} \cdot \frac{10}{I} = \frac{10}{\sqrt{2}} = 5\sqrt{2}\ V$

139. **(c)** The primary electromagnetic waves used as a diagnostic tool in medicine are X rays (used in radiography and CT scans). The wavelength range of X-rays falls precisely within the region of 1 mm down to 10^{-3} mm(10^{-9} m to 10^{-12} m).

140. **(d)** • Distance of Closest Approach

At closest approach:

$\frac{1}{2}mv^2 = \frac{k(2Ze^2)}{d}$

Thus,

$d \propto \frac{1}{v^2}$

If velocity is halved:

$d' = \frac{1}{(v/2)^2} / \frac{1}{v^2} \times d = 4d$

141. **(a)** Concave Lens Cut into Two Identical Plano-Concave Lenses

Original lens:

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

For a symmetric biconcave lens:

$\frac{1}{f} = -(\mu - 1)\frac{2}{R}$

After cutting, each plano-concave lens has one curved surface only:

$$\frac{1}{f'}=-(\mu-1)\frac{1}{R}$$
Hence,
$f'=2f=20\text{ cm}$

142. **(c)** Interference of Waves

For sustained interference, waves must have the same frequency and a constant phase difference.
$y_1=A_1\sin\omega t$
$y_2=A_2\sin 2\omega t$
(different frequency
$$y_3=A_3\cos\omega t=A_3\sin\left(\omega t+\frac{\pi}{2}\right)$$
(same frequency as y_1)
$$y_4=A_4\sin\left(\omega t+\frac{\pi}{3}\right)$$
(same frequency as y_1 and y_3,)
Therefore interference is possible among (I), (III), and (IV).

143. **(d)** Two Heaters in Series

Given ratings (P_1, V) and (P_2, V).
Resistances:
$$R_1=\frac{V^2}{P_1}, R_2=\frac{V^2}{P_2}$$
In series across V/2:
$$P=\frac{(V/2)^2}{R_1+R_2}$$
$$=\frac{V^2/4}{V^2\left(\frac{1}{P_1}+\frac{1}{P_2}\right)}$$
$$=\frac{1}{4}\cdot\frac{P_1P_2}{P_1+P_2}$$

144. **(c)** • In an unbiased p-n junction at equilibrium, no net current flows.
• Diffusion current moves majority carriers across the junction.
• The resulting electric field creates an opposing drift current.
• Therefore, diffusion and drift currents are equal and opposite.

145. **(d)** • Assertion is false: Diamagnetic atoms with filled shells have a net magnetic moment of zero.
• Reason is false: Every current-carrying loop always behaves as a magnetic dipole (M = NIA).

146. **(a)** • Assertion is true: Accelerated electrons show wave properties and undergo diffraction.
• Reason is true: Moving electrons exhibit wave-particle duality.
• Connection: The wave nature perfectly explains the diffraction pattern.

147. **(c)**• Assertion is true: Mass defect causes the nuclear mass to be less than its separated nucleons.
• Reason is false: Energy is released (not absorbed) when nucleons bind together.

148. **(b)** • Assertion is true: Energy levels are discrete due to angular momentum quantization.
• Reason is true: Electrostatic force provides the necessary centripetal force for stable orbits.
• Connection: The reason describes the mechanics but does not explain the quantization condition.

149. Given: Wavelength $(\lambda)=200\text{ nm}$

Stopping potential $V_s=0.80\text{ V}$
The energy of the incident radiation (E) is determined by its wavelength (λ). Using the relationship between energy, Planck's constant (k), and the speed of light (c):
$$E=\frac{hc}{\lambda}$$
Using the common approximation $(hc)=1240\text{eV}.\text{nm}$:
$$E=\frac{1240}{200}$$
$=6.20\text{eV}$

The photocurrent becomes zero at the stopping potential ($V_0 = 0.80$ V). This potential corresponds to the maximum kinetic energy (K_{max}) of the emitted photoelectrons:

$K_{max} = e \cdot V_0$

$= 0.80 eV$

According to Einstein's equation, the energy of the incident photon is the sum of the work function (Φ) and the maximum kinetic energy of the electrons:

$E = \Phi + K_{max}$

$\Phi = E - K_{max}$

$= 6.20 - 0.80$

$= 5.40 eV$

∴ The work function of the emitter is 5.40 eV .

150. **(A)** Given: $\lambda_1 = 400$ nm

$\lambda_2 = 600$ nm

$a = 1$ mm $= 10^{-3}$ m

$D = 1.5$ m

For coincidence of dark fringes:

$m_1\lambda_1 = m_2\lambda_2$

$m_1(400) = m_2(600)$

$\frac{m_1}{m_2} = \frac{600}{400}$

$\frac{m_1}{m_2} = \frac{3}{2}$

$m_1 = 3,\ m_2 = 2$

For small angles:

$y = \frac{m\lambda D}{a}$

$= \frac{m_1\lambda_1 D}{a}$

$= \frac{3 \times 100 \times 10^{-9} \times 1.5}{10^{-3}}$

$= \frac{1800 \times 10^{-9}}{10^{-3}}$

$= 1.8 \times 10^{-3}$ m

$= 1.8$ mm

∴ The least distance from the central maximum where the dark fringes of both wavelengths coincide is 1.8 mm .

(B) Given: $\lambda_1 = 440$ nm

$\lambda_2 = 660$ nm

$d = 0.6$ mm $= 6 \times 10^{-4}$ m

$D = 1.5$ m

For coincidence of bright fringes:

$n_1\lambda_1 = n_2\lambda_2$

$n_1(440) = n_2(660)$

$\frac{n_1}{n_2} = \frac{660}{440}$

$\frac{n_1}{n_2} = \frac{3}{2}$

$n_1 = 3, n_2 = 2$

For interference maxima:

$y = \frac{n\lambda D}{d}$

$= \frac{n_1\lambda_1 D}{d}$

$= \frac{3 \times 440 \times 10^{-9} \times 1.5}{6 \times 10^{-4}}$

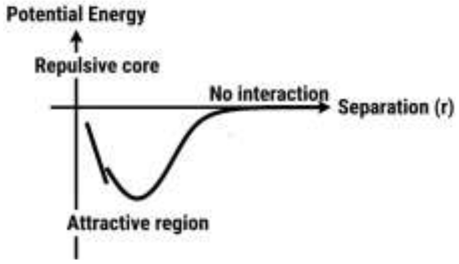
$= \dfrac{1980 \times 10^{-9}}{0.6 \times 10^{-3}}$
$= 3.3 \times 10^{-3}$ m
$= 3.3$ mm
∴ The least distance from the central maximum where the bright fringes due to both wavelengths coincide is 3.3 mm .

151. Let the side of the square be a.
Total wire length for N turns:
$L = N \times 4a$
$a = \frac{L}{4N}$ ....(i)
Area of square:
$A_5 = a^2$
$= \left(\frac{L}{4N}\right)^2$ ...[From eq. (i)]
$= \dfrac{L^2}{16N^2}$
Let radius be r,
Total wire length $(L) = N \times 2\pi r$
$r = \frac{L}{2\pi N}$ ....(ii)
Area of circle $(A_c) = \pi r^2$
$= \pi \frac{L}{(2\pi N)^2}$ ...[From eq. (ii)]
$= \dfrac{L^2}{4\pi N^2}$
Ratio of torques:
$\dfrac{\tau_s}{\tau_e} = \dfrac{A_s}{A_c}$
$= \dfrac{\frac{L^2}{16N^2}}{\frac{L^2}{4xN^2}}$
$= \dfrac{1}{16} \times 4\pi$
$= \dfrac{\pi}{4}$
$\therefore \dfrac{\tau_{square}}{\tau_{circle}} = \dfrac{\pi}{4}$

152. When an electric field is applied across a conductor, free electrons acquire a small net velocity called drift velocity. This causes an electric current. Drift velocity is very small because electrons undergo frequent collisions with lattice ions. Typical value:
$v_d \sim 10^{-4}$ to 10^{-3} m/s
So, order of magnitude:
$v_d \approx 10^{-4}$ m/s
• Let:
$n =$ Number of free electrons per unit volume
$A =$ Cross-sectional area
$v_d =$ Drift velocity
$e =$ Charge of electron
In time dt , electrons move a distance:
$dx = v_d dt$
Volume crossing area:
$dV = A \cdot dx = Avv_d dt$
Number of electrons $= nAv_d dt$
Charge $(d_q) = neAv\ _d dt$

$I = \frac{dq}{dt}$
$= neAv_d$

153.



Conclusion:
(1) Short Range Nature of Nuclear Force: Only a very small distance ($1 - 2$fm) is covered by the nuclear force. Potential energy gets closer to zero beyond this point, indicating negligible interaction.
(2) Repulsive Core at Small Distances: Potential energy increases significantly at very small separations, suggesting a powerful repelling force. This gives nuclei stability and keeps nucleons from falling into one another.

154. **(A)** Gauss's law:

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

Take a cylindrical "pillbox" of cross-sectional area A passing through the sheet.
By symmetry, the electric field is perpendicular to the sheet and has the same magnitude on both sides.
Flux through curved surface $= 0$
Flux through two flat faces:
$\Phi = EA + EA$
$= 2EA$
Charge enclosed:
$Q_{enc} = \sigma A$
$2EA = \frac{\sigma A}{\varepsilon_0}$
$E = \frac{\sigma}{2\varepsilon_0}$

(B) For two large, parallel thin sheets with identical surface charge density σ in air, the net electric field is:
(i) Inside (between) the sheets: The net electric field is zero. because the fields from each sheet $\left(E = \frac{\sigma}{2\varepsilon_0}\right)$ are equal and point in opposite direction. Hence ($E = 0$).
(ii) Outside the sheets: The net electric field is $\frac{\sigma}{\varepsilon_0}$ (pointing away from the sheets) as the fields from both sheets are equal and act in the same direction.

OR

(A) : Balanced Wheatstone Bridge Condition
A Wheatstone bridge consists of four resistors (P, Q, R, S) connected in a closed loop with a galvanometer connected between two opposite junctions.
- Let the current through the galvanometer be I_g.
- Under the balanced condition, no current flows through the galvanometer: $I_g = 0$.
- This happens when the electrical potential at both terminals of the galvanometer is equal.
- Applying Kirchhoff's laws gives the balanced bridge condition:

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

(B) : Net Resistance Between A and B
The network between nodes M and N forms a balanced Wheatstone bridge:
- The ratio of the arm resistances is $\frac{R}{R} = \frac{R}{R} = 1$.
- Therefore, no current flows through the central vertical resistor between O and P.
- We can remove the resistor OP from our calculations.

Simplification Steps:
(1) Upper branch ($M \to P \to N$) : Two resistors R in series:

$R_{upper} = R + R = 2R$

(2) Lower branch $(M \rightarrow O \rightarrow N)$: Two resistors R in series:

$R_{lower} = R + R = 2R$

(3) Parallel combination between M and N :

$$R_{MN} = \frac{2R \times 2R}{2R + 2R} = R$$

(4) Total Series Path ($A \rightarrow M \rightarrow N \rightarrow B$):

$R_{AB} = R_{AM} + R_{MN} + R_{NB}$

$R_{AB} = 2R + R + 3R = 6R$

155. When the battery is disconnected, the charge (Q) on the plates remains constant because there is no path for it to flow.

Here is how the properties change when the dielectric (dielectric constant $K > 1$) is removed:

(A) The capacitance (C) decreases. The capacitance of a parallel plate capacitor is $C = \frac{K\varepsilon_0 A}{d}$. Removing the dielectric means K drops to 1, so the capacitance decreases by a factor of $\frac{1}{K}$.

(B) The energy stored (U) increases. Using the formula $U = \frac{Q^2}{2C}$, we see that since Q is constant and C decreases, the energy stored increases. This extra energy comes from the work done by an external agent to pull the slab out against the electrostatic attraction of the plates.

(C) The potential difference (V) increases. Since $V = \frac{Q}{C}$ and Q is constant, the decrease in capacitance causes the potential difference to increase by a factor of K .

156. Given: Initial velocity $(u) = 3 \times 10^7$ m/s

Plate separation $(d) = 2$ cm $= 0.02$ m

Plate length $(I) = 3$ cm $= 0.03$ m

$m = 9.1 \times 10^{-31}$ kg

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

Electron enters midway, so vertical displacement:

$$y = \frac{d}{2}$$
$$= \frac{0.02}{2}$$
$$= 0.01 \text{ m}$$

Time of travel between plates $(t) = \frac{l}{u}$

$$= \frac{0.03}{3 \times 10^7}$$
$$= 10^{-9} \text{ s}$$

Vertical motion $(y) = \frac{1}{2}at^2$

$$\Rightarrow 0.01 = \frac{1}{2}a(10^{-9})^2$$
$$a = \frac{0.02}{10^{-18}}$$
$$= 2 \times 10^{16} \text{ m/s}^2$$

Electric force $(F) = ma = eE$

$$E = \frac{ma}{e}$$
$$= \frac{(9.1 \times 10^{-31}) \times (2 \times 10^{16})}{1.6 \times 10^{-19}}$$
$$E \approx 1.14 \times 10^5 \text{ V/m}$$

Potential difference $(V) = Ed$

$= 1.14 \times 10^5 \times 0.02$

$\approx 2.3 \times 10^3$ V

≈ 2.3kV

157. **(A)** During positive half-cycle:

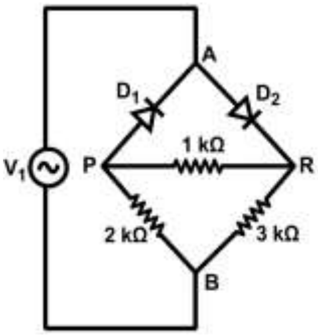
A is positive w.r.t. B.

Diode D_1 is reverse-biased.

Diode D_2 becomes forward-biased.

D_2 conducts because it is forward-biased.

(B)



(c) Peak input voltage:

$R_{eq} = \frac{3}{2} k\Omega$

$I = \frac{12}{3/2}$

$= \frac{12 \times 2}{3}$

$= \frac{24}{3}$

$= 8\ mA$

$R_{(1\Omega)} = 1 \times 4\ mA$

$= 4\ V$

$R_{(2k\Omega)} = 2k\Omega \times 4\ mA$

$= 8\ V$

$V_{(3k\Omega)} = 4\ mA \times 3k\Omega$

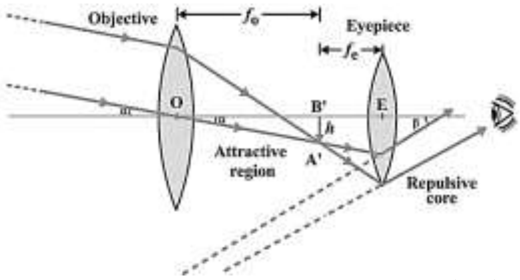
$= 12\ V$

158. Two major processes that take place during the formation of a p-n junction are diffusion and drift.

• Diffusion: In an n-type semiconductor, electrons are present in much higher concentration than holes, whereas in a p-type semiconductor, holes are present in much greater concentration than electrons. When the p-n junction is formed, the difference in concentration causes holes to move from the p-region to the n-region ($p \to n$) and electrons to move from the n-region to the p-region ($n \to p$). This movement of charge carriers across the junction results in the formation of a diffusion current.

• Drift: Drift of charge carriers occurs due to the electric field created at the junction. Because of the built-in potential barrier, an electric field is established from the n-region to the p-region. This electric field causes electrons on the p-side to move toward the n-side and holes on the n-side to move toward the p-side. As a result, a drift current is produced, which flows in the direction opposite to the diffusion current.

159. **(A) (i)**



(ii) Angular magnification (M) $= \frac{\text{Angle subtended by final image}}{\text{Angle subtended by object}}$

For normal adjustment:

$M = -\frac{f_0}{f_e}$

Negative sign indicates an inverted image.

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

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

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

160. **(i)** (1) The light must travel from a denser medium to a rarer medium.

(2) The angle of incidence must be greater than the critical angle for the pair of media.

(ii) Given refractive indices:

$n_A = n$

$n_B = \frac{3n}{4}$

$n_C = \frac{2n}{3}$

Using Snell's law:

$n_A \sin\theta = n_B \sin r$

$n\sin\theta = \frac{3n}{4}\sin r$

$\sin r = \frac{4}{3}\sin\theta$

For the beam to enter C :

$\sin r \leq \sin i_c$ ...(i)

Critical angle for B-C:

$\sin i_c = \frac{n_C}{n_B}$

$= \frac{(2n/3)}{(3n/4)}$

$= \frac{8}{9}$

Total internal reflection at B-C requires:

$\sin r \geq \frac{8}{9}$ ....(ii)

Substitute $\sin r = \frac{4}{3}\sin\theta$ in equation (ii),

$\frac{4}{3}\sin\theta \geq \frac{8}{9}$

$\sin\theta \geq \frac{2}{3}$

If $\sin\theta \geq \frac{2}{3}$, the beam undergoes total internal reflection at the B-C interface and never enters region C.

161. **(i) (b)**

• The torque on the coil remains constant irrespective of the coil's orientation during rotation due to radial magnetic field.

Explanation:

In a moving coil galvanometer, the deflecting torque acting on the coil is given by:

$\tau = nBIA\sin\theta$

For accurate measurement, torque must be proportional only to current and not depend on angle.

Problem with a uniform magnetic field. If the magnetic field is uniform, the torque depends on $\sin\theta$, so it changes with coil orientation. This makes the scale non-linear.

Use of radial magnetic field. In a radial magnetic field, the magnetic field lines remain perpendicular to the plane of the coil. Thus, the angle between the magnetic field and the coil's normal stays constant:

$\theta = 90°$

$\Rightarrow \sin\theta = 1$

So torque becomes:

$\tau = NBIA$

Which is independent of coil orientation.

(ii) (b)

• The best way to increase current sensitivity of a galvanometer is by increasing area of coil and magnetic field strength.
Explanation:
Current sensitivity:
$S = \frac{\theta}{I}$
$= \frac{nBA}{k}$
It increases with a larger area, a stronger magnetic field, more turns and a smaller torsional constant.
(iii) (A) (d)
• A moving coil galvanometer has a coil with area of cross-section $4.0 \times 10^{-3}\ m^2$ and number of turns 50 . The coil is rotating in a magnetic field of 0.25 T . The torque acting on the coil when a current of 5 A passes through it is 0.25 N m.
Explanation:
Given: Number of turns $(n) = 50$
Magnetic field $(B) = 0.25\ T$
Current $(I) = 5\ A$
Area $(A) = 4 \times 10^{-3}\ m^2$
Torque on coil $(\tau) = nBIA$
$= 50 \times 0.25 \times 5 \times 4 \times 10^{-3}$
$= 0.25 Nm$
OR
(B) (b)
• A galvanometer coil has a resistance of 15 and the meter shows full scale deflection for a current of 3 mA . The value of resistance required to convert it into a voltmeter of range $(0 - 12\ V)$ is 3985Ω.
Explanation:
Given: $G = 15\Omega$
$I_g = 3 \times 10^{-3}\ A$
$V = 12\ V$
$R_s = \frac{V}{I_g} - G$
$= \frac{12}{3 \times 10^{-3}} - 15$
$= 4000 - 15$
$= 3985\Omega$
(iv) (c)
• A galvanometer with coil of resistance 20Ω shows full scale deflection for a current of 5 mA . To convert it into an ammeter of range $(0 - 10\ A)$, a resistance of 0.01Ω should be connected in parallel with it.
Given: $G = 20\Omega$
$I_g = 5 \times 10^{-3}\ A$
$I = 10\ A$
For converting a galvanometer into an ammeter, use a shunt resistance:
$S = \frac{I_g G}{I - I_g}$
$= \frac{(5 \times 10^{-3}) \times 20}{10 - (5 \times 10^{-3})}$
$= \frac{0.005 \times 20}{10 - 0.005}$
$= \frac{0.1}{9.995}$
$\approx 0.01\Omega$
A shunt is always connected in parallel.

162. **(i) (c)** hv_1 and hv_2
Threshold frequency v_0 is where stopping potential becomes zero.
Work function $(\Phi) = hv0$

Hence, metals A and B have work functions $h\nu_1$ and $h\nu_2$.

(ii) (a)

• For radiation of frequency $\nu > \nu_2$ incident on the surfaces of A and B, the maximum kinetic energy of ejected electron is greater for metal A because it has a smaller work function.

Explanation:

Photoelectric equation is given as:

$K_{max} = h\nu - \Phi$

For the same frequency samaller work function gives larger kinetic energy.

From the graph, metal A has a smaller threshold frequency and a smaller work function.

(iii) (d)

• If the intensity of the incident radiation for both metals A and B , is doubled keeping its frequency constant, then the slope of the parallel lines will not change but more electrons will be emitted per second.

Explanation:

Slope of the stopping potential vs frequency graph:

$$\text{Slope } = \frac{h}{e}$$

It depends only on fundamental constants, not intensity. The intensity affects the number of emitted electrons (photoelectrons). Hence, the slope remains unchanged, and the emission rate increases.

(iv) (A) (c)

• The threshold frequency for a metal surface is ν_0. If radiation of frequency $3\nu_0$ illuminates the surface, the maximum kinetic energy (KE) of photoelectrons is E_1. If frequency were increased to $6\nu_0$, the maximum KE of photoelectrons becomes E_2. Then $\left(\frac{E_1}{E_2}\right)$ equals $2/5$.

The photoelectric equation is given as:

$K_{max} = h\nu - h\nu_0$

For the frequency $3\nu_0$:

$E_1 = h(3\nu_0 - \nu_0) = 2h\nu_0$

For frequency $6\nu_0$:

$E_2 = h(6\nu_0 - \nu_0) = 5\ h\nu_0$

$$\frac{E_1}{E_2} = \frac{2h\nu_0}{5h\nu_0}$$

$$= \frac{2}{5}$$

OR

(B) (a)

• Let m be the slope of the graph line for metal B. If e is the value of electron charge, then Planck's constant ' h ' is given by me.

Explanation:

From the stopping potential vs frequency graph:

$$V_5 = \frac{h}{e}\nu - \frac{\Phi}{e}$$

$\text{Slope (m)} = \frac{h}{e}$

$h = me$

163. **(A)** Distance of point from each charge $(d) = \sqrt{r^2 + a^2}$

Magnitude of field due to one charge $(E) = \frac{1}{4\pi\varepsilon_0}\frac{q}{d^2}$

Resultant field $\left(E_{eq}\right) = \frac{1}{4\pi\varepsilon_0}\frac{2qa}{(r^2+a^2)^{3/2}}$

Since $p = 2qa$;

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

The direction is opposite to the dipole moment.

For $r \gg a$:

$r^2 + a^2 \approx r^2$

$E_{eq} = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$

(B) Dipole axis along x -axis $(\vec{p}) = 2aq\hat{i}$

In a uniform field:

$\vec{F} = 0$

Torque $\vec{\tau} = \vec{p} \times \vec{E}$

Since both $\vec{p}$ and $\vec{E}$ are along $\hat{i}$:

$\vec{\tau} = 0$

OR

(A) Cells in parallel share the same terminal voltage.

Let,

Equivalent emf $= E$

Equivalent internal resistance $= r$

Using the current division principle:

$E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$

Multiply numerator and denominator by $r_1 r_2$:

$E = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$

Parallel combination of internal resistances:

$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2}$

$r = \frac{r_1 r_2}{r_1 + r_2}$

(B) Using formula:

$E_{eq} = \frac{E \cdot R + 3E \cdot R}{R + R}$

$= \frac{4ER}{2R}$

$= 2E$

Equivalent internal resistance $(r) = \frac{R \cdot R}{R + R}$

$= \frac{R}{2}$

Total resistance $(R_{total}) = 2R + \frac{R}{2}$

$= \frac{5R}{2}$

Current through 2R:

$I = \frac{E_{eq}}{R_{total}}$

$= \frac{2E}{5R/2}$

$= \frac{4E}{5R}$

164. **(A)** For refraction at a spherical surface:

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

Apply this to both surfaces of a thin lens.

For air to lens:

$\frac{\mu}{v_1} - \frac{1}{u} = \frac{\mu - 1}{R_1}$ ….(i)

For lens to air:

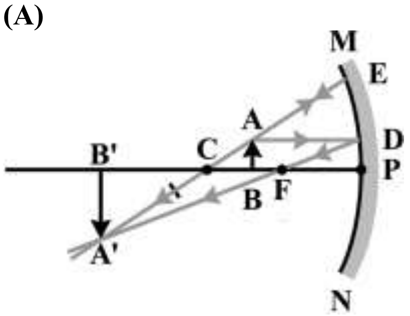
$\frac{1}{v} - \frac{\mu}{v_1} = \frac{1 - \mu}{R_2}$ ….(ii)

Adding equations (i) and (ii), and eliminating v_1 :
$$\frac{1}{v}-\frac{1}{u}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$
For focal length, $u=\infty$, so:
$$\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$
This is the lens maker's formula.

(B) The first lens L_1 has a focal length $f_1=40\ cm$, and the object distance is $u_1=-80\ cm$ (left of the lens).
Using the lens formula:
$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$
$$\frac{1}{v_1}-\frac{1}{-80}=\frac{1}{40}$$
$$\frac{1}{v_1}=\frac{1}{40}-\frac{1}{80}$$
$$\frac{1}{v_1}=\frac{1}{80}$$
$$v_1=80\ cm$$
The first image is formed 80 cm to the right of L_1.
The distance between L_1 and L_2 is 120 cm .
The image from L_1 acts as the object for L_2.
$$u_2=v_1-120$$
$$=80-120$$
$$=-40\ cm$$
The focal length $f_2=40\ cm$. Since the object is placed at the focus $(u_2=-f_2)$:
$$\frac{1}{v_2}-\frac{1}{-40}=\frac{1}{40}$$
$$\frac{1}{v_2}=\frac{1}{40}-\frac{1}{40}$$
$$\frac{1}{v_2}=0$$
$$v_2=\infty$$
The rays emerging from L_2 are parallel to the principal axis.
The distance between L_2 and L_3 is 20 cm .
Since the rays from L_2 are parallel ($u_3=\infty$), they will converge at the focus of L_3.
$$v_3=f_3=40\ cm$$
The final image is formed 40 cm to the right of L_3.
To find the distance from the object to the final image, we sum the distances along the axis:
Object to $L_1=80$ cm
L_1 to $L_2=120$ cm
L_3 to final image $=40$ cm
Total distance $=80+120+20+40$
$=260$ cm

OR

(A)



In this case, the image is real, inverted and magnified. The image is formed beyond the centre of curvature.
The mirror formula is given as:

$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

(B) Given: The object is kept 10 cm in front of the mirror, so $u = -10$ cm

A virtual image in a concave mirror is always erect, so the magnification is positive.

Two-fold magnification $(m) = +2$

Using the magnification formula for mirrors:

$m = -\frac{v}{u}$

$2 = -\frac{v}{-10}$

$2 = \frac{v}{10}$

$v = 2 \times 10$

$v = 20$

The positive sign indicates the virtual image is formed 20 cm behind the mirror.

By using the mirror formula:

$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

$= \frac{1}{20} + \frac{1}{-10}$

$= \frac{1}{20} - \frac{1}{10}$

$= \frac{1}{20} - \frac{2}{20}$

$= \frac{1-2}{20}$

$\frac{1}{f} = -\frac{1}{20}$

$f = -20$ cm

The focal length of the concave mirror is -20 cm . The negative sign confirms the mirror is concave.

165. **(A)** Faraday's First Law: Whenever the magnetic flux linked with a circuit changes, an emf is induced in the circuit.

Faraday's Second Law: The magnitude of the induced emf is equal to the rate of change of magnetic flux.

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

For a coil of N turns:

$e = -N\frac{d\phi}{dt}$

Negative sign indicates Lenz's law (direction opposes cause).

(B) The self-inductance (L) of an air-filled long solenoid is derived by calculating the total magnetic flux linkage through the coil when a current (I) flows through it. For a long solenoid, the magnetic field is considered uniform inside and negligible outside.

Using Ampere's Law, the magnetic field inside a long, air-cored solenoid is:

$B = \mu_0 nI \quad \ldots(i)$

The flux through one turn of area (A) is:

$\Phi = B \times A \quad \ldots(ii)$

$= (\mu_0 nI)A \quad$ [From eq. (i)]

The total flux linkage, denoted as λ, is the number of turns multiplied by the flux per turn:

$\lambda = N \times \Phi \quad \ldots(iii)$

$= N(\mu_0 nIA)$

$= (nl)(\mu_0 nIA)$ ... $[N = nl]$

By definition, self-inductance is the ratio of total flux linkage to the current:

$L = \frac{\lambda}{I}$

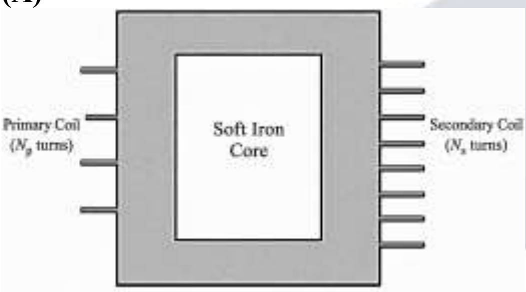
$= \frac{\mu_0 n^2 lAI}{I}$

$= \mu_0 n^2 lA$

The self-inductance of an air-filled long solenoid is:
$L = \mu_0 n^2 lA$
Or, in terms of total turns (N):
$L = \frac{\mu_0 N^2 A}{l}$
(C) Given: Length (l) $= 50$ cm $= 0.5$ m
Magnetic field (B) $= 4.0\text{mT} = 4 \times 10^{-3}$ T
Angular speed $60\text{rpm} = 1\text{rps}$
$\omega = 2\pi\text{rad/s}$
Emf induced in a rotating rod about one end:
$e = \frac{1}{2} B\omega l^2$
$= \frac{1}{2} \times 4 \times 10^{-3} \times 2\pi \times (0.5)^2$
$= 2 \times 10^{-3} \times 2\pi \times 0.25$
$= \pi \times 10^{-3}$
$\approx 3.14 \times 10^{-3}$ V
$e \approx 3.1\text{mV}$

OR

(A)



• When the terminals of the primary coil are connected to the source of alternating e.m.f., a varying current flows through it, which also produces a varying magnetic field in the core of the transformer. Thus, the magnetic field lines linked with the secondary coil vary and induce an e.m.f. in the secondary coil. The induced e.m.f. varies in the same manner as the applied e.m.f. in the primary coil varies, and thus, has the same frequency as that of the applied e.m.f.
• A transformer works on the principle of mutual induction. It changes the voltage levels without changing the frequency.
The output voltage $(V_s > V_p)$ is raised by a step-up transformer. This is achieved by the secondary coil having more turns than the primary coil$(N_s > N_p)$.
According to Faraday's law of induction, the emf induced in each turn is the same (assuming perfect flux linkage).
The induced emf in the primary coil is:
$\varepsilon_p = -N_p \frac{d\phi}{dt}$
The induced emf in the secondary coil is:
$\varepsilon_s = -N_s \frac{d\phi}{dt}$
For an ideal transformer, the terminal voltages V_p and V_s are approximately equal to the emfs. Dividing the two equations:
$\frac{V_s}{V_p} = \frac{N_s}{N_p} = k$
Where k is the transformation ratio. For a step-up transformer, $k > 1$.
(B) Given: $\frac{N_p}{N_s} = \frac{1}{5}$
$P = 5\text{ kW} = 5000\text{ W}$
$V_p = 200\text{ V}$
(i) Primary current $(P) = V_p I_p$

$\Rightarrow I_p = \frac{P}{V_p}$
$= \frac{5000}{200}$
$= 25$ A

(ii) Output voltage:
$\frac{V_s}{V_p} = \frac{N_s}{N_p}$
$V_s = \left(\frac{N_s}{N_p}\right)V_p$
$= 5 \times 200$
$= 1000$ V

166. **(d)** Formula for quantization of charge: $Q = n \cdot e$
Given charge (Q) : $1nC = 10^{-9}C$
Charge of a single proton (e): $1.6 \times 10^{-19}C$
Calculation:
$n = \frac{Q}{e} = \frac{10^{-9}}{1.6 \times 10^{-19}} = 6.25 \times 10^9$

167. **(d)** Total charge (Q): $N \cdot e = 10^{20} \times (1.6 \times 10^{-19}C) = 16C$
Total time (t): 2 minutes $= 2 \times 60$ s $= 120$ s
Average electric current (I):
$I = \frac{Q}{t} = \frac{16C}{120\text{ s}} \approx 0.133\text{ A} = 1.33 \times 10^{-1}\text{ A}$

168. **(d)**• According to Faraday's Law of Induction, an electric current is only induced in a loop when there is a change in the magnetic flux passing through it.
• Options (a), (b), and (c) describe stationary systems where the magnetic field remains constant, so no current is induced. Moving the magnet rapidly creates a changing magnetic field, inducing a current.

169. **(d)** This principle is the foundation of optical fibers.
Light enters the curved tube (fiber) at an angle larger than the critical angle, causing it to bounce repeatedly off the inner walls by reflecting entirely inside without losing energy.

170. **(c)** The work function $\phi_0 = \frac{hc}{550\text{ mm}}$ establishes a threshold wavelength (λ_0) of 550 mm - Photoelectric emission only happens if the incident wavelength is less than or equal to this value ($\lambda \leq 550$ nm).
Blue light has a wavelength of around $400 - 490$ nm (which is less than 550 nm , so it ejects electrons).
Red light has a much longer wavelength, around $620 - 750$ nm. Because $\lambda_{red} > \lambda_0$. the energy of the red photons is too low to overcome the work function, meaning no electrons will be emitted regardless of the light's intensity.

171. **(d)** An electron and a proton are accelerated through the same potential difference. Let λ_c and λ_p be the de Broglie wavelength associated with electron and proton respectively. Then λ_e/λ_p is:
• Formula: The de Broglie wavelength for a particle accelerated through a potential difference V is given by:
$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2mqV}}$
• Since both are accelerated through the same potential V and carry the same magnitude of charge q(e), we have:
$\lambda \propto \frac{1}{\sqrt{m}}$
• Therefore, the ratio is:
$\frac{\lambda_e}{\lambda_p} = \sqrt{\frac{m_p}{m_e}}$

172. **(c)** Suppose there is an atom that contains five energy levels. How many transitions are possible in which photons are emitted?
• Formula: The number of possible emission transitions from n energy levels is given by:

Number of transitions $= \frac{n(n-1)}{2}$

• Substituting $n = 5$:

Transitions $= \frac{5 \times (5-1)}{2} = \frac{20}{2} = 10$

173. **(b)** Which of the following particles do not exist in $_{92}U^{238}$ nucleus?

• Atomic number $(Z) = 92$ (Number of protons $= 92$)
• Mass number $(A) = 238$ (Total number of nucleons $= 238$)
• Number of neutrons $= A - Z = 238 - 92 = 146$
• Electrons exist outside the nucleus, not inside it.

174. **(a)** The main source for energy generation in the stars is -

Stars generate energy via nuclear fusion, where lighter hydrogen nuclei combine under extreme temperature and pressure to form heavier helium nuclei, releasing massive amounts of energy.

175. **(a)** In Bohr's model of hydrogen atom, the potential energy of the electron in the ground state is -

• Total Energy in ground state $(E_1) = -13.6eV$
• Potential Energy $(U) = 2 \times E_1 = 2 \times (-13.6eV) = -27.2eV$

176. **(b)** A n -type semiconductor is obtained by doping silicon with -

To create an n-type semiconductor, intrinsic silicon (tetravalent) must be doped with a pentavalent impurity (5 valence electrons) like Arsenic, Phosphorus, or Antimony. Boron, Indium, and Aluminium are trivalent impurities used for p-type semiconductors.

177. **(b)** When a forward biasing is applied across a junction diode, it -

In forward biasing, the external voltage opposes the built-in potential barrier, which narrows down the depletion region and decreases its width.

178. **(d)** Assertion (A): Displacement current does not have the same physical effect as conduction current = False

Displacement current produces a magnetic field just like conduction current.
Reason (R): The concept of displacement current is introduced only to satisfy Kirchhoff's rules.=False
It was introduced by Maxwell to make Ampere's law consistent and to explain electromagnetic waves.

179. **(c)** Assertion (A): In a series LCR circuit at resonance, the impedance equals the resistance R.=True

At resonance,
$X_L = X_C$
$Z = \sqrt{R^2 + (X_L - X_C)^2} = R$
Reason (R): At resonance, the capacitive reactance is not equal to the inductive reactance. =False
Actually,
$X_L = X_C$
at resonance.

180. **(a)** • Assertion: Frequency remains unchanged when light enters glass from air.=True

• Reason: Speed and wavelength both change in glass.=True
Since
$v = f\lambda$
and f remains constant, wavelength changes when speed changes.
The reason is consistent with and explains the assertion.

181. **(b)** • Assertion: Photoelectric effect demonstrates particle nature of light.= True

• Reason: Number of photoelectrons emitted depends on intensity. =True
However, this statement alone does not explain the particle nature. The particle nature is established mainly because electron emission depends on photon energy (frequency), not merely intensity.

182. Battery and Resistor

Given:
$E = 6V, r = 1\Omega, I = 0.5\ A$
(i) Using
$I = \frac{E}{R+r}$
$0.5 = \frac{6}{R+1}$
$R + 1 = 12$

$R = 11\Omega$

(ii) Terminal Voltage

$V = E - Ir$

$V = 6 - (0.5)(1)$

$V = 5.5V$

183. **(A).** Ray Along Principal Axis in a Spherical Mirror

A ray travelling along the principal axis strikes the mirror normally because the principal axis passes through the centre of curvature.

Hence angle of incidence $i = 0°$.

By the law of reflection,

$i = r = 0°$

Therefore the ray retraces its path.

The ray is reflected back along the same path.

OR

(B). Sign Convention for a Convex Lens

According to Cartesian sign convention:

(1) All distances are measured from the optical centre.

(2) Distances measured in the direction of incident light are positive.

(3) Distances measured opposite to the direction of incident light are negative.

(4) Heights above the principal axis are positive.

(5) Heights below the principal axis are negative.

For a convex lens:

$f > 0$

184. Refraction at a Convex Spherical Surface

Given:

$n_1 = 1, n_2 = 1.5$

$u = -50\text{ cm}, R = +20\text{ cm}$

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

$$\frac{1.5}{v} - \frac{1}{(-50)} = \frac{0.5}{20}$$

$$\frac{1.5}{v} + \frac{1}{50} = \frac{1}{40}$$

$$\frac{1.5}{v} = \frac{1}{40} - \frac{1}{50} = \frac{1}{200}$$

$v = 300\text{ cm}$

$v = +300\text{ cm}$

Nature: Real and formed inside the glass.

185. Threshold Frequency

• Definition

The minimum frequency of incident radiation required to eject photoelectrons from a metal surface is called threshold frequency (ν_0).

$h\nu_0 = \phi$

where ϕ is the work function.

• Dependence on Intensity

ν_0 does not depend on intensity

It depends only on the nature of the metal.

Variation of Photoelectric Current

For $\nu > \nu_0$.

Photoelectric current increases with intensity

because higher intensity means more photons strike the surface per second.

186. Difference Between n-type and p-type Semiconductors

n-type Semiconductor	p-type Semiconductor

Doped with pentavalent impurity (P, As,Sb)	Doped with trivalent impurity (B, Al, Ga)
Majority carriers: Electrons	Majority carriers: Holes
Minority carriers: Holes	Minority carriers: Electrons
Conduction mainly by electrons	Conduction mainly by holes
Donor impurity	Acceptor impurity

187. **(A) (i)** Derive Drift Velocity

When an electric field $\vec{E}$ is applied, force on an electron is

$\vec{F} = -e\vec{E}$

Hence acceleration,

$$\vec{a} = \frac{\vec{F}}{m} = -\frac{e\vec{E}}{m}$$

If τ is the mean relaxation time, then average drift velocity acquired between two successive collisions is

$\vec{v}_d = \vec{a}\tau$

$$\vec{v}_d = -\frac{e\vec{E}}{m}\tau$$

(ii) Although electrons are accelerated by the electric field, they frequently collide with lattice ions of the conductor.

These collisions continuously randomize their motion and prevent indefinite acceleration. As a result, electrons attain a constant average velocity called drift velocity.

Frequent collisions with lattice ions produce a steady average drift velocity.

OR

(B) Resistance

Definition

Resistance is the opposition offered by a conductor to the flow of electric current.

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

SI Unit

ohm (Ω)

Factors affecting resistance

At constant temperature, resistance depends on:

(1) Length l of conductor

(2) Area of cross-section A

(3) Nature of material (resistivity ρ)

Relation:

$$R = \rho\frac{l}{A}$$

188. **(A)** Given:

$I = 3A$

Distance from wire,

$r = 15\ \text{cm} = 0.15\ \text{m}$

Magnetic field due to long straight conductor:

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

$$B = \frac{4\pi \times 10^{-7} \times 3}{2\pi \times 0.15}$$

$B = 4 \times 10^{-6} T$

$B = 4\mu T$
Direction
Current is along +z-axis.
Using the Right-Hand Thumb Rule, at a point on the x-axis the magnetic field is along the yd direction.
Rule used:
Right-Hand Thumb Rule
(B) A current-carrying loop in a magnetic field experiences outward magnetic forces on all its elements.
These forces tend to increase the area enclosed by the loop.
For a given perimeter, the maximum area is enclosed by a circle.
Hence the loop changes into a circular shape.
The loop becomes circular to maximize its area under magnetic forces.

189. **(A)** Lenz's Law and Conservation of Energy
Lenz's law states that the induced current always flows in a direction that opposes the change in magnetic flux producing it.
If the induced current aided the change in flux, energy would be created without external work.
By opposing the change, external work has to be done, and the mechanical energy supplied is converted into electrical energy.
Thus,
Lenz's law is consistent with the law of conservation of energy.
(B) Magnetic Energy Density
Magnetic energy stored in an inductor:
$$U = \frac{1}{2}LI^2$$
For a solenoid,
$$L = \frac{\mu_0 N^2 A}{l}$$
And
$$B = \mu_0 \frac{N}{l} I$$
$$I = \frac{Bl}{\mu_0 N}$$
Substituting in U,
$$U = \frac{1}{2}\left(\frac{\mu_0 N^2 A}{l}\right)\left(\frac{Bl}{\mu_0 N}\right)^2$$
$$U = \frac{B^2 Al}{2\mu_0}$$
Volume of solenoid:
$V = Al$
Therefore,
$$u = \frac{U}{V} = \frac{B^2 Al/(2\mu_0)}{Al}$$
$$u = \frac{B^2}{2\mu_0}$$
where u is the magnetic energy per unit volume|

190. **(A)** Wavelength and Time Period of EM Wave
Given:
$f = 40MHz = 40 \times 10^6$ Hz
Speed of electromagnetic wave in free space:
$c = 3 \times 10^8$ m s^{-1}
Wavelength
$$\lambda = \frac{c}{f}$$
$$\lambda = \frac{3 \times 10^8}{40 \times 10^6} = 7.5 \text{ m}$$

$\lambda = 7.5$ m

Time Period

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

$T = \frac{1}{40 \times 10^6} = 2.5 \times 10^{-8}$ s

$T = 2.5 \times 10^{-8}$ s

(B) Magnetic Field

Given:

$E_{max} = 750$ N/C

For an electromagnetic wave,

$E = cB$

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

$B = \frac{750}{3 \times 10^8} = 2.5 \times 10^{-6}$ T

$B = 2.5 \times 10^{-6}$ T

Direction of Magnetic Field

Wave travels along +x-axis.

Electric field is along +y-axis.

Since

$\vec{E} \times \vec{B} =$ direction of propagation

$\hat{y} \times \hat{z} = \hat{x}$

Hence magnetic field is along +z-axis.

$\vec{B}$ is along the +z-axis

191. Coherent Sources of Light

• Definition

Coherent sources are sources that emit light waves of the same frequency (or wavelength) and maintain a constant phase difference.

Coherent sources have the same frequency and a constant phase difference.

Why are they required for interference?

A stable interference pattern is produced only when the phase difference between the waves remains constant.

If the phase difference changes randomly, bright and dark fringes disappear.

Coherent sources are necessary to obtain sustained interference fringes.

• Example in Daily Life

The colourful patterns seen in:

• Soap bubbles

• Thin oil films on water

are due to interference of light.

Example: Colours seen in a soap bubble or oil film on water.

192. Total Energy of Electron = −3.4eV

Given:

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

$\frac{13.6}{n^2} = -3.4$

$n^2 = 4$

$n = 2$

(i) Angular Momentum

According to Bohr's quantization:

$L_n = n\frac{h}{2\pi}$

For $n = 2$.

$L = 2\frac{h}{2\pi} = \frac{h}{\pi}$

$L = 2(1.055 \times 10^{-34})$

$L = 2.11 \times 10^{-34}$ J s

(ii) Potential Energy

For a hydrogen atom,

$U = 2E$

$U = 2(-3.4)$

$U = 6.8eV$

193. **(A)** Junction Diode as a Half-Wave Rectifier

Circuit

• A p-n junction diode is connected in series with a load resistance R_L across the secondary of an AC transformer.

• Working

• Positive Half Cycle

The diode is forward biased.

Current flows through the load resistance.

Output voltage appears across the load.

• Negative Half Cycle

The diode is reverse biased.

No current flows.

Output voltage is zero.

Thus only one half-cycle of AC is obtained across the load as pulsating DC.

A half-wave rectifier converts AC into pulsating DC using only one half-cycle.

(B) Efficiency $= 40\%$

Rectifier efficiency:

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100$$

Given:

$\eta = 40\%$

Therefore only 40% of the input AC power is converted into useful DC power.

The remaining

$100 - 40 = 60\%$

power is dissipated as heat in:

• diode resistance,

• transformer winding resistance,

• other circuit losses.

The remaining 60% power is lost mainly as heat in the rectifier circuit.

194. **(i) (b)**

• Dipole Moment

Charges:

q at $(a, 0)$

q at $(3a, 0)$

Distance between charges:

$d = 3a - a = 2a$

Dipole moment magnitude:

$p = qd = 2qa$

Direction is from $-q$ to $+q$, i.e. from $x = 3a$ to $x = a$, along $-x$-axis.

(ii) (b)

• Ratio of Electric Fields

At distance r :

Axial field:

$$E_1 = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$$

Equatorial field:

$$E_2 = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

Therefore,

$\frac{E_1}{E_2} = 2$

(iii) (A) (c)

• Potential Energy of Dipole

Given:

$p = 4 \times 10^{-9} C\ m$

$E = 5 \times 10^4\ N/C$

$\theta = 30°$

Potential energy:

$U = -pE\cos\theta$

$U = -(4 \times 10^{-9})(5 \times 10^4)\left(\frac{\sqrt{3}}{2}\right)$

$U = -1.73 \times 10^{-4}\ J$

Magnitude:

$1.73 \times 10^{-4}\ J$

OR

(B) (d)

• Dimensional Formula of Dipole Moment

$p = q \times d$

Charge:

$[q] = [AT]$

Distance:

$[L]$

Therefore,

$[p] = [LTA]$

(iv) (b)

• Direction of Torque

$\vec{\tau} = \vec{p} \times \vec{E}$

Cross product is perpendicular to both vectors.

Therefore torque is perpendicular to both $\vec{p}$ and $\vec{E}$.

195. **(i) (a)**

• The charged particle exhibiting this motion is:

• Explanation: According to the Right-Hand Rule, if a particle moves horizontally (e.g., East, $+\hat{\imath}$) in a vertically upward magnetic field ($+\hat{k}$), the cross product $\vec{v} \times \vec{B}$ points in the $-\hat{\jmath}$ direction (South). For the particle to move in an anticlockwise circle (when viewed from above), the centripetal force must point towards the North $(+\hat{\jmath})$. Since the force direction is opposite to $\vec{v} \times \vec{B}$, the particle must have a negative charge. Among the given options, only the electron is negatively charged.

(ii) (d)

• The direction of the magnetic force acting on the moving particle is given by:

• Explanation: The magnetic force on a moving charge is given by $\vec{F} = q(\vec{v} \times \vec{B})$, where the direction of the vector cross product is determined using the RightHand Rule.

(iii) (A) (c)

• If the velocity of the particle is doubled, the radius of the circle described will be:

• Explanation: The radius of a circular path in a magnetic field is given by the formula:

$R = \frac{mv}{qB}$

Since radius R is directly proportional to velocity $v(R \propto v)$, doubling the velocity doubles the radius (2R).

OR

(B) (c) A particle having charge $1\mu C$ is moving with a velocity of $5 \times 10^6\ ms^{-1}$ in a uniform magnetic field of 1 T . If the angle between the velocity and the magnetic field is 30°, the magnitude of the force on the particle will be:

• Explanation: The magnitude of the magnetic force is given by:

$F = qvB\sin\theta$

Substituting the given values:

$F = (1 \times 10^{-6} C) \times (5 \times 10^6\ ms^{-1}) \times (1\ T) \times \sin(30°)$

$F = 5 \times 0.5 = 2.5$ N

(iv) (b)

• The frequency of revolution of a particle of mass m and charge q, moving with speed v along a circular path of radius R, in magnetic field $\vec{B}$ will be:

• Explanation: The time period of revolution T is the total circumference divided by speed:

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

Substituting $R = \frac{mv}{qB}$ gives:

$$T = \frac{2\pi m}{qB}$$

Frequency (f) is the reciprocal of the time period ($f = \frac{1}{T}$):

$$f = \frac{qB}{2\pi m}$$

196. **(A) (i)** Relation between Electric Field ($\vec{E}$) and Force ($\vec{F}$):

The electric field $\vec{E}$ at a point is defined as the electrostatic force experienced per unit positive test charge placed at that point. If a charge q is placed at a point where the electric field due to charge Q is $\vec{E}$, the force $\vec{F}$ acting on it is:

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

(ii) Relation between Electric Field ($\vec{E}$) and Potential (V :

The electric field intensity at any point equals the negative gradient of the electrostatic potential at that point:

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

For a point charge Q at a distance r, the magnitude of the field and potential relate simply as:

$$E = \frac{V}{r}$$

(B) Let the three vertices of an equilateral triangle of side a be A, B, and C, each holding a charge q. We find the net force on the charge at vertex A.

(1) Force on A due to $B(\vec{F}_{AB})$:

$$F_{AB} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a^2}$$

(2) Force on A due to $C(\vec{F}_{AC})$:

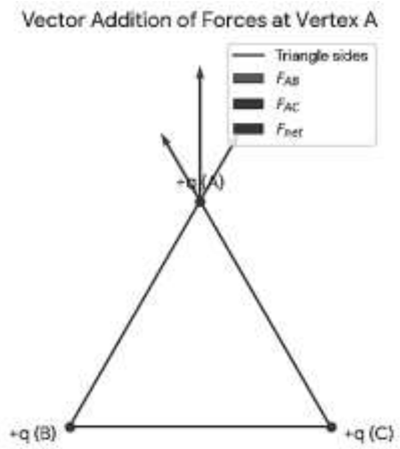
$$F_{AC} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a^2}$$

Let $F_0 = F_{AB} = F_{AC}$. Since the triangle is equilateral, the angle θ between these two repulsive forces is 60°. Using the vector addition formula, the magnitude of the net force F_{nct} is:

$$F_{net} = \sqrt{F_{AB}^2 + F_{AC}^2 + 2F_{AB}F_{AC}\cos 60^\circ}$$

$$F_{net} = \sqrt{F_0^2 + F_0^2 + 2F_0^2\left(\frac{1}{2}\right)} = \sqrt{3}F_0$$

$$F_{net} = \frac{\sqrt{3}}{4\pi\varepsilon_0}\frac{q^2}{a^2}$$



OR

(A) Derivation of Energy Stored in a Capacitor:

Let an uncharged capacitor of capacitance C be charged gradually to a final charge Q . At an intermediate stage, let the charge on the plates be q, meaning the potential difference across them is $v=\frac{q}{c}$.

The small amount of work done dW in transferring an additional charge dq is:

$$dW=v\cdot dq=\frac{q}{C}dq$$

Integrating from $q=0$ to $q=Q$ gives the total work done:

$$W=\int_0^Q\frac{q}{C}dq=\frac{1}{C}\left[\frac{q^2}{2}\right]_0^Q=\frac{Q^2}{2C}$$

This work is stored as electrostatic potential energy U :

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

Effect of a Dielectric Medium (K):

• Case 1: Battery remains connected (V is constant)

Capacitance increases to $C=KC_0$. The new energy becomes:

$$U=\frac{1}{2}CV^2=\frac{1}{2}(KC_0)V^2=KU_0$$

The energy stored increases by a factor of K.

• Case 2: Battery is disconnected (Q is constant)

Capacitance increases to $C=KC_0$. The new energy becomes:

$$U=\frac{Q^2}{2C}=\frac{Q^2}{2(KC_0)}=\frac{U_0}{K}$$

The energy stored decreases by a factor of K.

(B) Because each dielectric slab covers an area of $\frac{A}{2}$ and spans across the entire plate separation d, the setup forms a parallel combination of two distinct capacitors.

(1) Capacitance of the first region (C_1) :

$$C_1=\frac{K_1\varepsilon_0(A/2)}{d}=\frac{K_1\varepsilon_0A}{2d}$$

(2) Capacitance of the second region (C_2):

$$C_2=\frac{K_2\varepsilon_0(A/2)}{d}=\frac{K_2\varepsilon_0A}{2d}$$

The total effective capacitance C_{cff} is the sum of the two individual capacitances:

$$C_{cff}=C_1+C_2=\frac{K_1\varepsilon_0A}{2d}+\frac{K_2\varepsilon_0A}{2d}$$

$$C_{eff}=\frac{\varepsilon_0A}{2d}(K_1+K_2)$$

197. **(A)** Mutual Inductance

• Definition

Mutual inductance of two coils is the magnetic flux linked with one coil due to unit current flowing in the other coil.

Mathematically,

$$M = \frac{N_2\phi_{21}}{I_1}$$

or

$$e = -M\frac{dI}{dt}$$

where e is the induced emf in the secondary coil.

• SI Unit:- Henry (H)

Factors Affecting Mutual Inductance

(1) Number of turns in the coils (N_1, N_2)

(2) Area of cross-section of the coils

(3) Distance/separation between the coils

(4) Nature (permeability) of the medium/core between them

(Any two factors may be written.)

(B) Numerical

Given:

$l = 1m$

$r = 2cm = 0.02m$

$N_1 = 2000$

$N_2 = 1000$

Area of solenoid:

$A = \pi r^2 = \pi(0.02)^2 = 1.256 \times 10^{-3}\ m^2$

Mutual inductance:

$$M = \mu_0\frac{N_1N_2A}{l}$$

$$M = (4\pi \times 10^{-7})\frac{(2000)(1000)(1.256 \times 10^{-3})}{1}$$

$M \approx 3.16 \times 10^{-3}H$

$M = 3.16 \times 10^{-3}H$

or

$M = 3.16mH$

OR

(A) Pure Inductive AC Circuit

For a pure inductor L,

$$v = L\frac{di}{dt}$$

Let

$i = I_0 \sin\omega t$

Then

$v = L\omega I_0 \cos\omega t$

$$v = V_0\sin\left(\omega t + \frac{\pi}{2}\right)$$

Hence voltage leads current by

$\frac{\pi}{2}rad(90°)$

Inductive Reactance

The opposition offered by an inductor to AC is called inductive reactance.

$X_L = \omega L = 2\pi fL$

Unit:- Ω

(B) Given

$E = 140\sin(314t)$

Comparing with

$E = E_0\sin\omega t$

we get

$E_0 = 140\ V$

$\omega = 314 rad\ s^{-1}$

(i) RMS Voltage

$$V_{rms} = \frac{E_0}{\sqrt{2}}$$

$$V_{rms} = \frac{140}{\sqrt{2}}$$

$$V_{rms} \approx 99 \text{ V}$$

(ii) Frequency

$$\omega = 2\pi f$$

$$f = \frac{314}{2\pi}$$

$$f \approx 50 \text{ Hz}$$

$$f = 50 \text{ Hz}$$

198. **(A)** Single Slit Diffraction

For single-slit diffraction, the angular width of the central maximum is

$$\theta = \frac{2\lambda}{d}$$

where

- λ = wavelength of light
- d = slit width

(i) When slit width is increased

Since

$$\theta \propto \frac{1}{d}$$

Increasing d decreases θ.

Angular width decreases

(ii) When distance between slit and screen is increased

Angular width

$$\theta = \frac{2\lambda}{d}$$

does not contain screen distance D.

Angular width remains unchanged

(Though linear width on the screen increases.)

(iii) When smaller wavelength is used

Since

$$\theta \propto \lambda$$

decreasing λ decreases θ.

Angular width decreases

(B) Given:

$$\lambda = 700 \text{ nm} = 700 \times 10^{-9} \text{ m}$$

For first minimum,

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

Given

$$\theta = 30^\circ$$

$$d\sin 30^\circ = \lambda$$

$$d \times \frac{1}{2} = 700 \times 10^{-9}$$

$$d = 1400 \times 10^{-9}$$

$$d = 1.4 \times 10^{-6} \text{ m}$$

or

$$d = 1.4 \mu m$$

OR

(A) Reflecting Telescope

Working

- A large concave mirror (objective) collects light from a distant object.
- It forms a real, inverted image near its focus.

• An eyepiece magnifies this image.
• The final image is formed at infinity (normal adjustment) or at the least distance of distinct vision.
Advantages over Refracting Telescope
(1) No chromatic aberration because reflection is independent of wavelength.
(2) Large aperture can be made, giving greater light-gathering power and resolving power.
(B) Magnifying Power
Given:
$f_o = 125$ cm
$f_e = 5$ cm
(i) Final image at infinity
$$M = \frac{f_o}{f_e}$$
$$M = \frac{125}{5}$$
$$M = 25$$
(ii) Final image at 25 cm
$$M = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$$
Where
$D = 25$ cm
$$M = \frac{125}{5}\left(1 + \frac{5}{25}\right)$$
$$M = 25(1.2)$$
$$M = 30$$