1. **(d)** Using $I=\frac{E}{R+r}$
For $R=2\Omega$:
$E=0.9(2+r)$
For $R=7\Omega$:
$E=0.3(7+r)$
Equate:
$0.9(2+r)=0.3(7+r)$
$1.8+0.9r=2.1+0.3r$
$0.6r=0.3\Rightarrow r=0.5\Omega$
2. **(d)** For motion in a magnetic field,
$R=\frac{mv}{qB}$
So, $R\propto\frac{m}{q}$
New radius:
$R'=\frac{(2m)}{(q/2)}\cdot\frac{v}{B}=\frac{2m}{q/2}\cdot\frac{v}{B}=\frac{4m}{q}\cdot\frac{v}{B}=4R$
3. **(b)** Sodium and Calcium: Both of these materials are paramagnetic because they have unpaired electrons in their atomic structure. In the presence of an external magnetic field, these unpaired electrons align with the field, causing a weak attraction.
4. **(c)** Given galvanometer resistance $\mathrm{G}=50\Omega$
For range $0-2\mathrm{V}$, series resistance $\mathrm{R}_1=1\mathrm{k}\Omega=1000\Omega$
Using voltmeter relation:
$\mathrm{V}=\mathrm{I_g}(\mathrm{G}+\mathrm{R})$
From first case:
$2=\mathrm{I_g}(50+1000)=\mathrm{I_g}(1050)\Rightarrow\mathrm{I_g}=\frac{2}{1050}$
For new range $0-10$ V :
$10=\mathrm{I_g}(50+\mathrm{R}_2)$
Substitute $\mathrm{I_g}$:
$10=\frac{2}{1050}(50+\mathrm{R}_2)$
$50+\mathrm{R}_2=\frac{10\times1050}{2}=5250$
$\mathrm{R}_2=5250-50=5200\Omega=5.2\mathrm{k}\Omega$
5. **(a)** Using mutual inductance relation:
$e=M\frac{dI}{dt}$
Given:
$e=2\mathrm{mV}=2\times10^{-3}\ \mathrm{V}$
$\frac{dI}{dt}=5\ \mathrm{A/s}$
$M=\frac{e}{dI/dt}=\frac{2\times10^{-3}}{5}=0.4\times10^{-3}\mathrm{H}=0.4\mathrm{mH}$
6. **(b)** Ultraviolet (UV) rays are used to purify water because they can kill or inactivate microorganisms like bacteria and viruses without adding chemicals.
7. **(d)** For a compound microscope (final image at infinity, relaxed eye):
Magnification
$\mathrm{M}=\frac{\mathrm{L}}{\mathrm{f_o}}\times\frac{\mathrm{D}}{\mathrm{f_e}}$
Where:
• $\mathrm{L}=10$ cm (tube length)
• $\mathrm{f_o}=1$ cm (objective)

• $f_e = 2$ cm (eyepiece)
• $D = 25$ cm (least distance of distinct vision)

$$M = \frac{10}{1} \times \frac{25}{2} = 10 \times 12.5 = 125$$

8. **(a)**• K_{max} is the maximum kinetic energy (eV_0).
• hv is the energy of the incident photon.
• Φ is the work function (hv_0).
From the provided graph:
(1). The x-intercept represents the threshold frequency (v_0).
(2). Metal A has the lowest threshold frequency, meaning it has the lowest work function.
(3). Since $K_{max} = hv - \Phi$, for a constant incident frequency (v), the metal with the smallest work function (Φ) will yield the highest kinetic energy.
Therefore, metal A will produce photo-electrons with the maximum kinetic energy.

9. **(c)** For hydrogen atom:

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

First excited state $\Rightarrow n = 2$:

$$E = \frac{-13.6}{4} = -3.4 eV$$

Using:
$K = -E, U = 2E$
$K = 3.4 eV, U = -6.8 eV$

10. **(c)** In YDSE, position of maxima depends on wavelength:
$y_n = n\lambda$
In a medium of refractive index μ, wavelength becomes:

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

So,

$$y_n' = n\frac{\lambda}{\mu}$$

For coincidence with 6th maximum in air:

$$n\frac{\lambda}{\mu} = 6\lambda$$

$$n = 6\mu = 6 \times \frac{4}{3} = 8$$

11. **(a)** The nucleon-nucleon potential energy curve has its minimum (most stable point) at about 0.8 fm .

12. **(b)** Given:
• Si atoms density $= 5 \times 10^{28}\ m^{-3}$
• Doping = 1ppm of Sb (donor → n-type)
• Hole concentration in doped crystal:
$p = 4.5 \times 10^9 m^{-3}$
Step 1: Donor concentration
$1ppm = 10^{-6}$
$N_D = 10^{-6} \times 5 \times 10^{28} = 5 \times 10^{22} m^{-3}$
Step 2: Use mass action law
$n \cdot p = n_i^2$
Since Sb is donor dopant and very large compared to intrinsic level:
$n \approx N_D = 5 \times 10^{22}$
Step 3: Calculate n_i
$n_i^2 = (5 \times 10^{22})(4.5 \times 10^9)$
$n_i^2 = 22.5 \times 10^{31} = 2.25 \times 10^{32}$
$n_i = \sqrt{2.25 \times 10^{32}} = 1.5 \times 10^{16}$

13. **(c)** The Assertion is true because the field vectors align along OC, but the Reason is false because the potential at the center is actually zero.

14. **(a)** Assertion (A): True
A magnetic field does not change the speed (hence energy) of a charged particle.
Reason (R): True
Magnetic force is always perpendicular to velocity, so work done is zero.
Since R correctly explains A:

15. **(c)** Assertion (A): True
If the two coherent sources are infinitely close ($d \to 0$), fringe width $\beta = \frac{\lambda D}{d}$ becomes very large ($\to \infty$), so no distinct fringes are observed.
Reason (R): False
Fringe width is inversely proportional to separation (d), not directly proportional.

16. **(d)** Assertion (A): False
For a scattering angle of 180° (head-on collision), the impact parameter is zero, not maximum.
Reason (R): False
Impact parameter does depend on the atomic number (Z) of the target nucleus (as seen in Rutherford scattering relation).

17. (A) All four charges are at equal distance from the centre. Opposite corners have equal charges:
- $+1\mu C$ at A and C → forces on centre charge cancel
- $-2\mu C$ at B and D → forces on centre charge cancel

So net force = 0
(B) Distance of centroid from each vertex:
$$r = \frac{a}{\sqrt{3}} = \frac{10 \text{ cm}}{\sqrt{3}}$$
Electric field at centroid due to one charge:
$$E = \frac{kq}{r^2}$$
All three charges are equal and due to symmetry their electric field vectors are at 120^∘, so their vector sum:
$$E_{net} = 0$$

18. Derivation
Consider a straight conductor of length l carrying current I in a uniform magnetic field B.
(1). Force on one electron: $f = -e(v_d \times B)$, where v_d is the drift velocity.
(2). Total electrons: $N = nAl$ (where n is number density, A is area).
(3). Total Force: $F = Nf = (nAl)[-e(v_d \times B)]$.
(4). Final Expression: Since $I = nAev_d$, the expression becomes:
$F = I(l \times B)$
Magnitude: $F = BIl\sin\theta$
Zig-Zag Form
Yes, it is valid.
• Justification: In a uniform magnetic field, the total force depends only on the vector sum of all small length elements (dl). This sum equals the straight-line displacement L from the start to the end of the conductor. Thus, $F = I(L_{effective} \times B)$.

19. For a telescope in normal adjustment:
Magnifying power
$$M = \frac{f_o}{f_e} = \frac{150}{5} = 30$$
Image formed by objective
In normal adjustment, the objective forms the image at its focal plane, so distance = 150 cm

20. (A) Wavelength of emitted radiation
Energy difference:
$$\Delta E = 2.55\text{eV}$$
Using:
$$\lambda = \frac{hc}{\Delta E} \approx \frac{1240}{2.55} \text{ nm} \approx 486 \text{ nm}$$
(B) Series

Wavelength ≈ 486 nm lies in the Balmer series (visible region).

21. Using Bohr's quantization:

$$mvr = \frac{nh}{2\pi} \Rightarrow n = \frac{2\pi mvr}{h}$$

Substitute values:

$m = 6.0 \times 10^{24}, v = 3.0 \times 10^{4}, r = 1.5 \times 10^{11}, h = 6.626 \times 10^{-34}$

$mvr = 6 \times 3 \times 1.5 \times 10^{24+4+11} = 27 \times 10^{39} = 2.7 \times 10^{40}$

$$n = \frac{2\pi \times 2.7 \times 10^{40}}{6.626 \times 10^{-34}} \approx \frac{16.96 \times 10^{40}}{6.626 \times 10^{-34}} \approx 2.56 \times 10^{74}$$

22. (A) Einstein's photoelectric equation

$h\nu = \phi + K_{max}$

or

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

where

h = Planck's constant,

ν = frequency of incident light,

ϕ = work function,

K_{max} = maximum kinetic energy .

Millikan's verification:

• He measured stopping potential V_0 for different frequencies.

• Using $K_{max} = eV_0$, he plotted V_0 vs ν.

• Obtained a straight line: slope $= h/e$, intercept $= -\phi/e$.

• This experimentally confirmed Einstein's equation.

(B) Threshold frequency

• From equation:

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

• For emission, $K_{max} \geq 0$

So,

$$h\nu \geq \phi \Rightarrow \nu \geq \nu_0 = \frac{\phi}{h}$$

• ν_0 is the threshold frequency.

• If $\nu < \nu_0$, photon energy is insufficient → no emission occurs, regardless of intensity.

Explanation:

Each electron needs minimum energy (ϕ) to escape. If incident light cannot supply this energy, emission is impossible.

23. (A) Electric flux

Electric flux is the dot product of electric field and area vector, i.e., the measure of field passing through a surface:

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

Dimensions:

$[\Phi] = [E][A] = (N/C)(m^2) = ML^3\,T^{-3}\,A^{-1}$

(B) Electric flux

Side = 1 cm = 10^{-2} m

$A = (10^{-2})^2 = 10^{-4}\ m^2$

$\vec{E} = 100\hat{\imath}, \hat{n} = 0.8\hat{\imath} + 0.6\hat{k}$

$\vec{A} = A\hat{n}$

$\Phi = \vec{E} \cdot \vec{A} = 100 \times 10^{-4} \times (0.8) = 8 \times 10^{-3}\ N \cdot m^2/C$

24. (A)(i) Lenz's Law:

The direction of induced current is such that it opposes the change in magnetic flux that produces it.

Justification (energy conservation):

If induced current did not oppose the change, it would aid the change, causing energy to be created without external work → violates conservation of energy. Hence opposition is necessary.

(ii) Induced e.m.f. (centre to end):

$$e = \frac{1}{2}B\omega l^2$$

Given:

$B = 2\ T, f = 60 rev/s \Rightarrow \omega = 2\pi f = 120\pi rad/s$
Length from centre to end $l = 1$ m
$e = \frac{1}{2} \times 2 \times 120\pi \times (1)^2 = 120\pi \approx 377$ V

OR

(B) (i) Ampere's Circuital Law:
The line integral of magnetic field around a closed path equals μ_0 times the net current enclosed:
$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc}$
It relates magnetic field to the current producing it.
(ii) Net magnetic field at midpoint:
Distance from each wire = 0.1 m
Magnetic field due to a long straight wire:
$B = \frac{\mu_0 I}{2\pi r}$
$B_1 = \frac{\mu_0 \cdot 5}{2\pi \cdot 0.1}, B_2 = \frac{\mu_0 \cdot 10}{2\pi \cdot 0.1}$
At midpoint, fields are opposite (same current direction), so:
$B_{net} = B_2 - B_1 = \frac{\mu_0(10-5)}{2\pi \cdot 0.1}$
$B_{net} = \frac{4\pi \times 10^{-7} \cdot 5}{2\pi \cdot 0.1} = 1 \times 10^{-5}$ T
Direction: Same as field due to the 10 A wire (using right-hand rule)

25. Given:
- $\vec{v} = (1.0 \times 10^7)\hat{\imath} + (0.5 \times 10^7)\hat{\jmath}$
- $\vec{B} = (0.5mT)\hat{\jmath} = 0.5 \times 10^{-3}\hat{\jmath}T$

Step 1: Velocity component causing circular motion
Only the component perpendicular to B contributes:
Since B is along $\hat{\jmath}$, the perpendicular component is:
- $v_1 = 1.0 \times 10^7$ m/s (along $\hat{\imath}$)

Parallel component:
- $v_| = 0.5 \times 10^7$ m/s → causes linear motion

So path is helical (circular + linear).
Step 2: Radius of circular path
$r = \frac{\frac{twF_1}{cB}}{cB}$
Using:
- $m = 9.1 \times 10^{-31}$ kg
- $e = 1.6 \times 10^{-19}$C
- $B = 0.5 \times 10^{-3}T$
- $v_1 = 1.0 \times 10^7$

$r = \frac{9.1 \times 10^{-31} \times 10^7}{1.6 \times 10^{-19} \times 0.5 \times 10^{-3}}$
$r \approx 0.114$ m
Step 3: Linear motion check
Yes, because $v_{||} \neq 0$, electron moves forward - helical path
Step 4: Linear distance in one revolution
Time period:
$T = \frac{2\pi m}{cB}$
$T = \frac{2\pi \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19} \times 0.5 \times 10^{-3}} \approx 7.1 \times 10^{-8}s$
Linear distance:
$d = v_l T = (0.5 \times 10^7)(7.1 \times 10^{-8}) \approx 0.355$ m

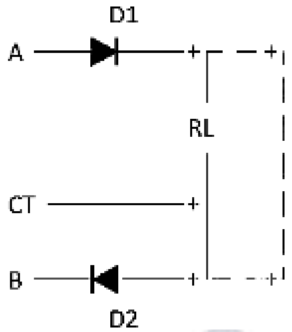
26. (A) (i) Infrared rays are known as 'heat waves' because they are readily absorbed by water molecules in most materials, increasing their thermal motion and raising the temperature.

(ii) Ultraviolet (UV) rays are absorbed by the ozone layer in the atmosphere, which protects life on Earth from their harmful ionizing effects.

(B)Infrared rays (heat waves):
• Production: By hot bodies (e.g., heated filament/electric heater)
• Detection: Thermopile / bolometer
Ultraviolet rays:
• Production: Electric discharge in gases (e.g., mercury vapour lamp)
• Detection: Photographic plate / photoelectric cell

27. (A) The $p-n$ junction diode is suitable for rectification primarily due to its unidirectional conductivity. Here are the two key characteristics that enable this:

(1). Low Resistance in Forward Bias: When the positive terminal of a battery is connected to the p-side and the negative to the n-side, the depletion layer narrows. This allows majority charge carriers to flow easily across the junction, making the diode act like a closed switch (conducting state).
(2). High Resistance in Reverse Bias: When the polarity is reversed, the depletion layer widens, preventing the flow of majority carriers. Only a negligible minority leakage current flows, making the diode act like an open switch (non-conducting state).
(B) Full Wave Rectifier (centre-tapped type):
Circuit:



Working:
• Positive half-cycle: End A is positive w.r.t. CT → D1 conducts, D2 off → current flows through RL in one direction.
• Negative half-cycle: End B is positive → D2 conducts, D1 off → current again flows through RL in same direction.
Thus both half-cycles produce current in the same direction, giving a full-wave (pulsating DC) output.
Key point: Output frequency = 2 × input frequency.

28. (A) A doped semiconductor is electrically neutral:
Doping adds equal positive and negative charges. For example, donor atoms give free electrons but become positively charged ions; acceptor atoms create holes but become negatively charged ions. Net charge = 0 → electrically neutral.
(B) No net current in p-n junction at equilibrium:
Diffusion current (due to concentration difference) is exactly balanced by drift current (due to built-in electric field). Hence total current = 0.
(C) Reverse current is independent of voltage:
Reverse current is due to minority carriers, whose number is fixed at a given temperature. Increasing reverse voltage does not increase their number significantly, so current remains almost constant.

29. **(i)(d)** A polar molecule has a permanent dipole moment due to unequal sharing of electrons.
• $O_2, H_2,\ N_2$: homonuclear → non-polar
• HCl : different atoms with electronegativity difference → polar
(ii)(b)
(iii)(b)
For an isolated charged capacitor, charge Q remains constant.
When a dielectric is inserted:
• Capacitance C increases
• Energy $U=\frac{Q^2}{2C}$ → decreases
• Electric field inside dielectric $E=\frac{E_0}{k}$ → decreases

(iv)(A)(c)
The dielectric slab (thickness $d/5$) fills part of the gap, so the capacitor behaves like two capacitors in series:
• Dielectric part: thickness $d/5$, dielectric constant K
• Air part: thickness $4d/5$
Equivalent capacitance:
$$\frac{1}{C}=\frac{d/5}{K\varepsilon_0 A}+\frac{4d/5}{\varepsilon_0 A}=\frac{d}{5\varepsilon_0 A}\left(\frac{1}{K}+4\right)$$
$$C=\frac{5\varepsilon_0 A}{d\left(4+\frac{1}{K}\right)}=\frac{5K}{4K+1}\cdot\frac{\varepsilon_0 A}{d}$$
Since $C_0=\frac{\varepsilon_0 A}{d}$,
$$C=\frac{5K}{4K+1}C_0$$
OR
(B)(d)
For the same battery, voltage V is constant. Energy $U=\frac{1}{2}C_{\text{eq}}V^2$, so energy $\propto$ equivalent capacitance.
Series combination:
$$C_s=\frac{(2C_0)(6C_0)}{2C_0+6C_0}=\frac{12C_0^2}{8C_0}=\frac{3}{2}C_0$$
Parallel combination:
$$C_p=2C_0+6C_0=8C_0$$
Ratio of energies:
$$\frac{U_s}{U_p}=\frac{C_s}{C_p}=\frac{\frac{3}{2}C_0}{8C_0}=\frac{3}{16}$$
30. (i) (c) Critical angle C for medium to medium is:
$$\sin C=\frac{n_2}{n_1}$$
For glass $\rightarrow$ water:
$$\sin C=\frac{1.33}{1.5}\approx 0.887\Rightarrow C\approx 62.5^\circ$$
Now:
• Critical angle for glass-air $(\theta_1)\approx 42^\circ$
• Critical angle for water-air $(\theta_2)\approx 49^\circ$
So:
$$C_{\text{glass-water}}>\theta_2$$
(ii)(c) When light enters a denser medium:
• Speed decreases
• Frequency v remains unchanged
• Since $v=\frac{c}{\lambda}$, wavelength λ decreases
(iii)
(A) (d) Critical angle C depends on refractive index:
$$\sin C=\frac{n_{\text{water}}}{n_{\text{glass}}}$$
Refractive index is higher for smaller wavelength (violet > blue > ⋯ > red). So for violet light, n_{glass} is maximum $\Rightarrow \sin C$ is minimum $\Rightarrow C$ is minimum.
OR
(B) (d) At minimum deviation, the path of light inside the prism is symmetric, so:
$$r_1=r_2=\frac{A}{2}$$
Thus the angle of refraction at the second surface depends only on prism angle A, not on wavelength.
So for all colours:
$$r_R=r_Y=r_V$$

(iv) (d) Based on the physics of refraction and the geometry of the prism, the correct answer is (d)undergo total internal reflection.
Here is the step-by-step breakdown:
(1). Find the Critical Angle ($\boldsymbol{\theta_c}$)
The critical angle for a medium is the angle of incidence above which total internal reflection occurs.
• Given refractive index $(\mu) = \sqrt{2}$
• Formula: $\sin\theta_c = \frac{1}{\mu} = \frac{1}{\sqrt{2}}$
• Therefore, $\boldsymbol{\theta}_c = 45^\circ$.
(2). Determine the Angle of Incidence at face AC
• The ray is incident normally on face AB. This means it enters the prism without bending and travels straight to face AC .
• In the right-angled triangle formed by the ray, the vertex A, and the point of incidence on AC :
• The angle at A is 60°.
• The angle at the normal to AB is 90°.
• Therefore, the angle the ray makes with the surface AC is 30° (since $180-90-60=30$).
• The angle of incidence (i) is the angle between the ray and the normal to face AC.
• $i = 90^\circ - 30^\circ = 60^\circ$.
(3).Conclusion
Since the angle of incidence (60°) is greater than the critical angle (45°), the ray cannot refract out of the prism. Instead, it will undergo total internal reflection back into the prism.

31. (A)

(i) Equipotential Surfaces for a Dipole
For an electric dipole, the equipotential surfaces are not concentric spheres. Near each charge, they are nearly spherical, but as you move further away, they bulge and become more complex. Between the two charges, the surfaces are crowded, indicating a stronger electric field. The perpendicular bisector of the dipole axis is a flat plane where the potential is zero.
(ii) Potential Energy in an External Field
When two charges $+q$ and q are placed in an external field **E**, the total potential energy (U) is the sum of the work done to bring each charge into the field and the mutual interaction energy between them:
$$U = q[V(x_1) - V(x_2)] - \frac{1}{4\pi\epsilon_0}\frac{q^2}{r}$$
Since $q\left(V(x_1) - V(x_2)\right)$ represents the interaction of the dipole with the external field ($-\mathrm{p}$. E), the expression is:
$$U = -\mathrm{p}\cdot\mathrm{E} - \frac{1}{4\pi\epsilon_0}\frac{q^2}{r}$$
(iii) Calculation of Change in Potential Energy
The potential energy of a dipole is $U = -pE\cos\theta$.
• Initial state $(\theta_1 = 0^\circ)$:
$U_i = -pE\cos 0^\circ = -pE$
• Final state $(\theta_2 = 60^\circ)$:
$U_f = -pE\cos 60^\circ = -0.5pE$
Change in Potential Energy (ΔU):
$\Delta U = U_f - U_i = -0.5pE - (-pE) = 0.5pE$
Substituting values:
$\Delta U = 0.5 \times (4\times10^{-30}\mathrm{C\ m}) \times (10^3\ \mathrm{V/mi})$
$\Delta U = 2\times10^{-27}\ \mathrm{J}$

OR

(B) (i) Electric Field of a Uniformly Charged Spherical Shell
Using Gauss' Law: $\oint \mathrm{E}\cdot dA = \frac{q_{\text{enclosed}}}{\epsilon_0}$
(1).Outside the shell ($r > R$):
Consider a spherical Gaussian surface of radius r. The total charge enclosed is $q = \sigma(4\pi R^2)$,
• By symmetry, **E** is radial and constant on the surface.
• $E(4\pi r^2) = \frac{\sigma(4\pi R^2)}{\epsilon_0}$

• $E=\frac{\sigma R^2}{\epsilon_0 r^2}$ (or $E=\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$)
• Observation: The shell behaves like a point charge at its center.
(2).Inside the shell ($r<R$):
Consider a spherical Gaussian surface of radius r inside the shell.
• Since all charge resides on the surface, $q_{\text{enclosed}}=0$.
• $E(4\pi r^2)=0$
• $E=0$
(ii) Net Electric Field Between Two Parallel Wires
Given:
• Wire AB: $\lambda_1=+\lambda$
• Wire CD: $\lambda_2=-2\lambda$
• Distance $(d)=1$ m
• Midpoint distance from each wire $(r)=0.5$ m
Field Magnitudes:
The electric field due to a long wire at distance r is $E=\frac{\lambda}{2\pi\epsilon_0 r}$.
• E_1 (from AB): Points away from AB (towards CD).
$$E_1=\frac{\lambda}{2\pi\epsilon_0(0.5)}=\frac{\lambda}{\pi\epsilon_0}$$
• E_2 (from CD): Points towards CD (away from AB) because the charge is negative.
$$E_2=\frac{2\lambda}{2\pi\epsilon_0(0.5)}=\frac{2\lambda}{\pi\epsilon_0}$$
Net Electric Field (E_{net}):
Since both fields point in the same direction (from AB toward CD):
• $E_{\text{net}}=E_1+E_2=\frac{\lambda}{\pi\epsilon_0}+\frac{2\lambda}{\pi\epsilon_0}$
• $E_{\text{net}}=\frac{3\lambda}{\pi\epsilon_0}$ N/C
Direction:
The net field is directed perpendicularly towards the wire CD.

32. (A)
(i) Identification of elements
• For X: V and I are in phase → pure resistor (R)
• For Y: V leads I by $\pi/4$ → inductive circuit (L)
• For Z : I leads V by $\pi/4$ → capacitive circuit (C)
$\mathrm{X=R, Y=L, Z=C}$
(ii) Impedance of series R-L-C circuit
In series:
• Resistance $=R$
• Inductive reactance $=X_L=\omega L$
• Capacitive reactance $=X_C=\frac{1}{\omega C}$
Net reactance:
$X=X_L-X_C$
Impedance:
$$Z=\sqrt{R^2+(X_L-X_C)^2}$$
$$Z=\sqrt{R^2+\left(\omega L-\frac{1}{\omega C}\right)^2}$$
Current:
$$I=\frac{V}{Z}$$
Variation with frequency (ω):
• At low ω: X_C large → current small
• At high ω: X_L large → current small
• At a particular ω : $X_L=X_C$ → current maximum (resonance)

Graph: Current vs frequency is a peak curve (resonance curve).
(iii) Conditions in series LCR circuit
(a) Impedance minimum:
Occurs at resonance:
$$X_L = X_C \Rightarrow \omega L = \frac{1}{\omega C}$$
$$\omega = \frac{1}{\sqrt{LC}}$$
At this point:
$Z = R$ (minimum)
(b) Wattless current:
Power $P = VI\cos\phi$
For wattless current:
$\cos\phi = 0 \Rightarrow \phi = 90^\circ$
This happens when:
• Circuit is purely inductive ($X_L \gg R, X_C$) or
• purely capacitive ($X_C \gg R, X_L$)
• Voltage and current are 90° out of phase, so average power = 0

OR

(B)(i) Construction and working of a transformer
Construction:
A transformer consists of:
• A soft iron laminated core (to reduce eddy current loss)
• Two insulated coils wound on the core:
• Primary coil (P) with N_p turns
• Secondary coil (S) with N_s turns
The primary is connected to an AC source, and the secondary is connected to a load.
Working principle:
A transformer works on mutual induction.
When AC flows in the primary coil, it produces a changing magnetic flux in the core.
• This changing flux links the secondary coil and induces an emf in it (Faraday's law).
Derivation of relation between voltages and turns:
Let:
• V_p, V_s = primary and secondary voltages
• N_p, N_s = number of turns in primary and secondary
From Faraday's law:
$$V_p \propto N_p \frac{d\Phi}{dt}, V_s \propto N_s \frac{d\Phi}{dt}$$
Dividing:
$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$
$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$
This is the transformer equation.
• If $N_s > N_p$: step-up transformer
• If $N_s < N_p$: step-down transformer
(ii) Four causes of energy loss in a real transformer
(1) Copper loss (I^2R loss):
Resistance of windings causes heat loss: I^2R.
(2) Eddy current loss:
Changing magnetic flux induces circulating currents in the core, producing heat (reduced by laminating the core).
(3) Hysteresis loss:
Energy lost in repeatedly magnetizing and demagnetizing the core material.
(4) Leakage of magnetic flux:
Not all flux produced in primary links the secondary, reducing efficiency.

33. (A) (i) Using Huygens' Principle, secondary wavelets from the boundary form the refracted wavefront. From geometry:

$$\frac{\sin i}{\sin r}=\frac{v_1}{v_2}=\frac{n_2}{n_1}$$

Hence verified Snell's Law:

$$n_1 \sin i = n_2 \sin r$$

(ii) Fringe width:

$$\beta=\frac{\lambda D}{d}=3\text{ mm}$$

4th dark fringe:

$$y=\left(4-\frac{1}{2}\right)\beta=3.5\times 3=10.5\text{ mm}$$

OR

(B)(i) Single slit diffraction (short)

When light passes through a narrow slit, it spreads and forms a pattern of a bright central maximum with alternating dark and faint bright fringes on both sides. The central fringe is the widest and most intense.

(ii) Concave mirror (object between pole and focus)

Using mirror formula:

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

For object between pole and focus, $u<f$, so solving gives:

- v is positive → image forms behind the mirror
- Magnification $m=-\frac{v}{u}>1$

Hence, the image is virtual, erect, and enlarged.

34. (c) Total potential energy = sum of pairwise energies:

$$U=\frac{1}{4\pi\varepsilon_0}\left(\frac{q\cdot q}{2a}+\frac{q(-2q)}{a}+\frac{q(-2q)}{a}\right)$$

$$=\frac{1}{4\pi\varepsilon_0}\left(\frac{q^2}{2a}-\frac{2q^2}{a}-\frac{2q^2}{a}\right)$$

$$=\frac{1}{4\pi\varepsilon_0}\left(\frac{q^2}{2a}-\frac{4q^2}{a}\right)=\frac{1}{4\pi\varepsilon_0}\left(-\frac{7q^2}{2a}\right)$$

$$=-\frac{7q^2}{8\pi\varepsilon_0 a}$$

35. (b) For identical conducting spheres, charge distributes equally after contact.

Let initial charge on $B_3 = x$.

Total initial charge:

$$-7+4+x=-3+x$$

After contact, all three have equal charge -2 pC , so total final charge:

$$3\times(-2)=-6\text{pC}$$

By conservation of charge:

$$-3+x=-6\Rightarrow x=-3\text{pC}$$

36. (a), (b)

37. (c) In the Bohr model of hydrogen atom:

$$r_n=n^2a_0$$

So, $r_n \propto n^2$

38. (c) Use the right-hand thumb rule.

- Current flows from east to west.
- Point is above the wire.
- Curl fingers in direction of magnetic field → at the point above, direction comes towards north.

39. (a) Diamagnetic materials have very small negative magnetic susceptibility.

40. (b) For converting a galvanometer into an ammeter:

$$I_gG=(I-I_g)S$$

Given:

$G = 100\Omega, S = 0.1\Omega, I = 1A$
$I_g \cdot 100 = (1 - I_g) \cdot 0.1$
$100I_g = 0.1 - 0.1I_g \Rightarrow 100.1I_g = 0.1$
$I_g = \frac{0.1}{100.1} \approx 10^{-3}\text{ A} = 1\text{ mA}$

41. **(a)** Magnetic field at center of loop A:
$B = \frac{\mu_0 I}{2R}$
Flux through loop B:
$\Phi = B \cdot \text{ Area of B} = \frac{\mu_0 I}{2R} \cdot \pi r^2$
Given $r = \frac{R}{20} \Rightarrow r^2 \propto R^2$
$\Phi \propto \frac{1}{R} \cdot R^2 = R$

42. **(d)** Explanation:
The inductance value is indicated by the slope of the graph between the inductive reactance X_L and the angular frequency (ω).
Additionally, the slope can be found using $\tan\theta$, where θ is the angle formed by the slope of the $XL - \omega$ graph and (ω). Based on the graph,
$L_1 = \tan 30^\circ = \frac{1}{\sqrt{3}}$
and $L_2 = \tan 60^\circ = \sqrt{3}$
So, $\frac{L_1}{L_2} = \frac{\frac{1}{\sqrt{3}}}{\sqrt{3}} = \frac{1}{3}$

43. **(a)** In an electromagnetic wave, the electric field $\vec{E}$ and magnetic field $\vec{B}$ oscillate in phase.
So, phase difference $= 0$

44. **(b)** Magnetic flux:
$\Phi = NBA = NB_0 A\cos\left(\frac{2\pi t}{T}\right)$
Induced emf:
$e = -\frac{d\Phi}{dt}$
$e \propto \sin\left(\frac{2\pi t}{T}\right)$
Magnitude is maximum when:
$\sin\left(\frac{2\pi t}{T}\right) = 1$
$\frac{2\pi t}{T} = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \ldots$
$t = \frac{T}{4}, \frac{3T}{4}, \frac{5T}{4}, \cdots = \frac{nT}{4}$

45. **(d)** In the Balmer series, as wavelength decreases (moving toward the series limit):
• Energy difference between levels decreases in spacing → lines get closer together
• Transition probability decreases → intensity becomes weaker

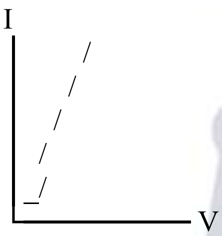
46. **(d)** Assertion (A): False - Zinc does not emit electrons under yellow light because its frequency is below the threshold frequency.
Reason (R): False - The photon energy of yellow light is less than the work function of zinc, not more.
Correct conclusion:
Both A and R are false.

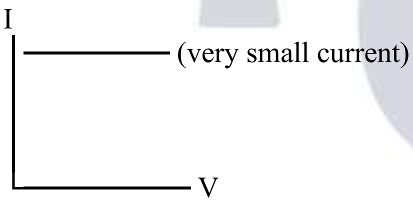
47. **(c)** Assertion (A): True
• Metals have positive temperature coefficient (resistance increases with temperature).
• p-type semiconductors have negative temperature coefficient (resistance decreases with temperature).
Reason (R): False

• In metals, charge carriers are electrons (negative), but in semiconductors both electrons and holes contribute; sign of carriers is not the reason for temperature coefficient behavior. The temperature dependence is due to change in mobility and number of carriers, not charge sign.

48. **(a)** Assertion (A): True
• In a conductor, electrons do not all move in one direction; their motion is random with a small net drift.
Reason (R): True
• Drift velocity is indeed superimposed on the large random thermal motion of electrons.
Explanation of link:
R correctly explains A because the net drift arises from random motion plus a small directed velocity due to an electric field.

49. **(c)** Assertion (A): True
• In interference and diffraction, energy is redistributed: bright fringes have higher intensity and dark fringes have lower intensity.
Reason (R): False
• Energy is conserved in both interference and diffraction. There is only redistribution of energy, not loss.

50. (i) Forward bias
+ ———|>|——— -
p n
(p connected to,+ n to -)
(ii) Reverse bias
+ ———|<|——— -
n p
(p connected to -, n to +)
I-V Characteristics
Forward bias


Reverse bias


• Forward: current increases after threshold voltage
• Reverse: very small current until breakdown

51. De Broglie wavelength:
$$\lambda = \frac{h}{\sqrt{2mqV}}$$
Given same wavelength for proton and α-particle:
$$\sqrt{m_p q_p V_1} = \sqrt{m_\alpha q_\alpha V_2}$$
Square both sides:
$$m_p q_p V_1 = m_\alpha q_\alpha V_2$$
For proton: $m_p, q_p = e$
For α-particle: $m_\alpha = 4m_p, q_\alpha = 2e$
Substitute:
$$m_p e V_1 = 4m_p \cdot 2e \cdot V_2$$
$$V_1 = 8V_2$$

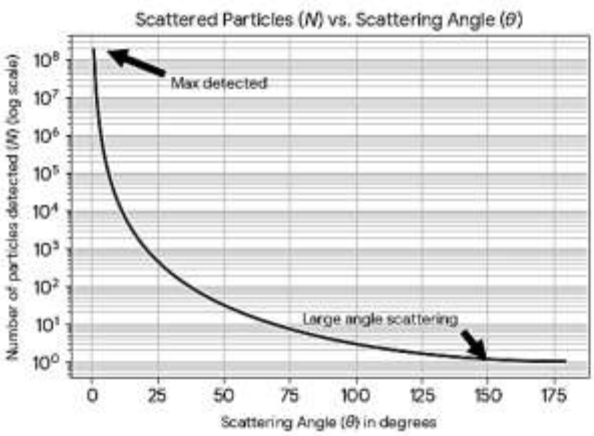
52. For an equilateral prism, angle $A = 60^\circ$.
Ray is incident normally on first face ⇒ inside prism it goes straight and strikes second face with:
$i = 60^\circ$
For the emergent ray to just graze the surface, angle of incidence at second face equals critical angle C :
$C = 60^\circ$
Critical angle relation (glass to medium):
$$\sin C = \frac{\mu_{medium}}{\mu}$$
$$\sin 60^\circ = \frac{\mu_m}{\mu}$$
$$\frac{\sqrt{3}}{2} = \frac{\mu_m}{\mu}$$
53. Let resistances be R_1, R_2.
Given power ratings at voltage V :
$$P_1 = \frac{V^2}{R_1}, P_2 = \frac{V^2}{R_2}$$
So,
$$R_1 = \frac{V^2}{P_1}, R_2 = \frac{V^2}{P_2}$$
(1) Series connection
Total resistance:
$$R_s = R_1 + R_2 = \frac{V^2}{P_1} + \frac{V^2}{P_2}$$
Current:
$$I = \frac{V}{R_s}$$
Power consumed:
$$P_s = I^2 R_s = \frac{V^2}{R_s}$$
$$P_s = \frac{V^2}{\frac{V^2}{P_1} + \frac{V^2}{P_2}} = \frac{1}{\frac{1}{P_1} + \frac{1}{P_2}}$$
$$P_s = \frac{P_1 P_2}{P_1 + P_2}$$
(2) Parallel connection
In parallel, each heater gets full voltage V, so:
$$P = P_1 + P_2$$
54. **(A)** Using refraction at spherical surface:
$$\frac{1}{v} \approx -0.0875 \Rightarrow v \approx -11.4 \text{ cm}$$
OR

(B) Refracting telescope (normal adjustment)
Given:
Distance between lenses:
$f_o + f_e = 1.00$ m
Magnifying power:
$$M = \frac{f_o}{f_e} = 19$$
So:
$f_o = 19 f_e$
Substitute:
$19 f_e + f_e = 1 \Rightarrow 20 f_e = 1 \Rightarrow f_e = 0.05 \text{ m} = 5 \text{ cm}$
$f_o = 19 \times 0.05 = 0.95 \text{ m} = 95 \text{ cm}$
55. **(A)** Fission vs Fusion

• Fission: Heavy nucleus splits into smaller nuclei (e.g., U-235, Pu-239).
• Fusion: Light nuclei combine to form a heavier nucleus (e.g., hydrogen → helium).
(B) Energy from 1 gPu − 239
Number of atoms:
$$N = \frac{6.02 \times 10^{23}}{239}$$
Total energy:
$$E = N \times 180 \approx 4.5 \times 10^{23} \text{MeV}$$

56. Given:
$$\vec{E} = (10x + 4)\hat{i}$$
Work done per unit charge:
$$W = -\int \vec{E} \cdot d\vec{l}$$
(i) From (5,0) to (10,0)
Only x changes:
$$W = -\int_3^{10} (10x + 4)dx$$
$$= -|5x^2 + 4x|_5^{10}$$
At 10:
$$5(100) + 40 = 540$$
At 5:
$$5(25) + 20 = 145$$
$$W = -(540 - 145) = -395J$$
(ii) From (5,0) to (5,10)
Here x is constant ⇒ E is along x-axis, but displacement is along y-axis:
$$\vec{E} \cdot d\vec{l} = 0$$
$$W = 0$$

57. Graph (N vs θ) - Geiger-Marsden experiment



Two conclusions
(1). Most α-particles pass straight or with small deflection → atom is mostly empty space.
(2). Very few particles scatter at large angles → positive charge and mass are concentrated in a small nucleus.
Distance of closest approach
At closest approach:
• Kinetic energy of α-particle is completely converted into electrostatic potential energy.
$$\frac{1}{4\pi\varepsilon_0} \cdot \frac{2Ze^2}{r_0} = \frac{1}{2}mv^2$$
Solving:
$$r_0 = \frac{1}{4\pi\varepsilon_0} \cdot \frac{4Ze^2}{| \; mv^2}$$

58. To find the current in branch BM from the circuit in image_a6dbb8.png, follow these steps:
(1). Simplify the Right-Hand Network

Starting from the far right, we calculate the equivalent resistance to simplify the nodes connected to node B:
• Loop D-E-F-G: Resistors R, 2R, and R are in series (4R), which is in parallel with the 4R. resistor across DG. This simplifies to 2R.
• Loop C-H-G-D: The previous 2R result is in series with the 2R resistor CD(4R), which is in parallel with the 4R resistor CH. This also simplifies to 2R.
• Since there is no resistance between B and C, node B is effectively connected to ground via a 2R equivalent resistance.
(2). Nodal Analysis at Node B
Set the bottom wire to 0 V (ground). Let V_B be the potential at node B . Using Kirchhoff's Current Law:

$$\frac{V_B - 10E}{3R} + \frac{V_B - 6E}{4R} + \frac{V_B}{2R} = 0$$

Multiply the entire equation by 12R :

$$4(V_B - 10E) + 3(V_B - 6E) + 6V_B = 0$$

$$13V_B = 58E \Longrightarrow V_B = \frac{58E}{13}$$

(3).Final Calculation for Branch BM
The current I_{BM} is the flow through the 4R resistor and 6E battery:

$$I_{BM} = \frac{V_B - 6E}{4R} = \frac{\frac{38E}{13} - \frac{78E}{13}}{4R} = \frac{20E}{52R} = -\frac{5E}{13R}$$

59. Magnetic field due to the current carrying loop,

$$B_1 = \frac{\mu_0 I}{2R} \text{ ... (at its centre)}$$

$$\Rightarrow B_1 = \frac{\mu_0 \times 1}{2 \times 10 \times 10^{-2}} \text{ ... (into the plane of the paper)}$$

Magnetic field due to the current carrying wire,

$$B_2 = \frac{\mu_0 I}{2\pi r}$$

$$\Rightarrow B_2 = \frac{\mu_0 \times I}{2\pi \times 20 \times 10^{-2}} T$$

Now, according to the question,

$B_1 = B_2$

So, $\frac{\mu_0}{2\times10\times10^{-2}} = \frac{\mu_0 I}{2\pi\times20\times10^{-2}}$

$\Rightarrow I = 2\pi$ A

$\Rightarrow I = 6.28$ A

To produce a net magnetic field of zero at 0 , the current should flow in the +x direction, and the magnetic field should be directed outward from the paper plane.

60. (i) FM radio broadcast:
Radio waves - wavelength $\approx$ 1 m to 10^3 m (FM band $\approx$ few metres)
(ii) Detection of fracture in bones:
X-rays - wavelength $\approx 10^{-8}$ m to 10^{-12} m
(iii) Treatment of muscular strain:
Infrared radiation - wavelength $\approx 10^{-3}$ m to 7×10^{-7} m

61. **(A)** (i) Mutual inductance:
It is the property of two coils by which a change of current in one coil induces an emf in the other.

$$M = \frac{e}{dI/dt}$$

SI unit: henry (H)
(ii) Coaxial solenoids:

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

(because only the smaller cross-sectional area πr_1^2 links the flux)
(B) Ferromagnetic materials & ferromagnetism
Ferromagnetic materials: Strongly magnetised materials like iron, cobalt, nickel.
Ferromagnetism: Explained by domain theory.
• In unmagnetised state, domains are randomly oriented → net magnetism = 0

• In external field, domains align in one direction → strong magnetisation
(Result: material becomes strongly magnetised)

62. (i) (b) When a pentavalent impurity (such as Arsenic or Antimony) is added to a pure semiconductor like Ge or Si , four of its valence electrons form covalent bonds with the neighboring semiconductor atoms. The fifth electron is left weakly bound. The energy required to liberate this electron to make it a free charge carrier is approximately 0.01 eV for Ge and 0.05 eV for Si. This small amount of energy is easily available even at room temperature.

(ii) (d) Given:
Intrinsic carrier concentration:
$n_i = 2.0 \times 10^{10}\ cm^{-3}$
Hole concentration after doping:
$p = 8 \times 10^3\ cm^{-3}$
For a semiconductor:
$np = n_i^2$
Step 1: Find electron concentration n
$$n = \frac{n_i^2}{p}$$
$$n = \frac{(2.0 \times 10^{10})^2}{8 \times 10^3}$$
$$n = \frac{4 \times 10^{20}}{8 \times 10^3}$$
$n = 0.5 \times 10^{17} = 5 \times 10^{16}\ cm^{-3}$
Step 2: Convert to m^{-3}
$1\ cm^{-3} = 10^6\ m^{-3}$
$n = 5 \times 10^{16} \times 10^6 = 5 \times 10^{22}\ m^{-3}$

(iii) (A) (c)
In a p-n junction:
• Electrons (majority in n-region) move to p-region
• Holes (majority in p-region) move to n-region
So, correct statement is:

OR

(B) (a) Initially during formation:
• Concentration difference is high → diffusion current is large
• Electric field is not yet strong → drift current is small

(iv) (d) Given:
$V = 0.5\sin(100\pi t)$
Step 1: Find input frequency
Compare with:
$V = V_0\sin(\omega t)$
So,
$\omega = 100\pi$
$$f = \frac{\omega}{2\pi} = \frac{100\pi}{2\pi} = 50\ Hz$$
So input AC frequency = 50 Hz
Step 2: Output frequency
Half-wave rectifier:
• Output frequency = same as input
$f = 50\ Hz$
Full-wave rectifier:
• Output frequency = double the input
$f = 2 \times 50 = 100\ Hz$

63. (i) (b) Given:
• Convex (converging) lens: $f_1 = +20cm = +0.20m$
• Concave (diverging) lens: $f_2 = -15cm = -0.15m$
Step 1: Convert to power

$$P=\frac{1}{f(\text{ in m})}$$
$$P_1=\frac{1}{0.20}=5D$$
$$P_2=\frac{1}{-0.15}=-\frac{20}{3}D$$
Step 2: Total power
$$P=P_1+P_2=5-\frac{20}{3}$$
$$P=\frac{15-20}{3}=\frac{-5}{3}D$$
(ii) (c) Using lens maker's formula:
$$\frac{1}{f}=(\mu-1)\left(\frac{1}{R}-\frac{1}{-2R}\right)=(\mu-1)\frac{3}{2R}$$
Given $f=\frac{4}{3}R$:
$$\frac{3}{4R}=(\mu-1)\frac{3}{2R}$$
Cancel:
$$\mu-1=\frac{1}{2}\Rightarrow\mu=\frac{3}{2}$$
(iii) (a)• When a lens is dipped in water, the refractive index difference decreases.
• So, power decreases ⇒ focal length increases.
$$f\propto\frac{1}{(\mu_{lens}-\mu_{medium})}$$
(iv) (A)(1). Lens L : Parallel rays converge at its focus, 10 cm to the right of L.
(2). Mirror M : The image is 30 cm from $M(40-10=30)$. Since 30 cm is the Center of Curvature (2f), the light reflects back to the same point.
(3).Position: This point is 10 cm to the right of the lens.

OR

(B)(1). Lens L_1 : Rays converge 16 cm to the right of L_1.
(2). Lens L_2 : The object for L_2 is 24 cm to its left $(40-16=24)$.
(3). Lens Formula for L_2 :
$$\frac{1}{v}-\frac{1}{-24}=\frac{1}{12}\Longrightarrow\frac{1}{v}=\frac{1}{12}-\frac{1}{24}=\frac{1}{24}$$
$v=24$ cm

64. (A) (i) Convex mirror
Ray diagram (idea):
• One ray parallel → appears from focus F
• One ray towards centre C → reflects back
• Reflected rays diverge, their extensions meet behind mirror → virtual, erect, diminished image between P and F
Mirror formula (result):
$$\frac{1}{f}=\frac{1}{v}+\frac{1}{u}$$
(ii) Multi-component lenses
Used to reduce chromatic & spherical aberration and improve sharpness and image quality.
(iii) Compound microscope
Given: $M=200, f_e=2$ cm
Eyepiece magnification:
$$M_e=\frac{25}{2}=12.5$$
Total magnification:
$$M=M_o\times M_e\Rightarrow M_o=\frac{200}{12.5}=16$$

OR

(B)(i) • Wavefront: Locus of points in same phase.

•Ray: Line normal to wavefront showing direction of light.

(ii) Huygens' principle:

Every point on a wavefront acts as a source of secondary wavelets; the new wavefront is the envelope of these wavelets.

Reflection: From construction, angle of incidence = angle of reflection and incident ray, reflected ray, normal lie in same plane.

(iii) Given: $d = 3\ \text{mm}, D = 1\ \text{m}, 5\ \text{mm} = \frac{5}{2}\beta$

So, $\beta = 2\ \text{mm}$

$$\lambda = \frac{\beta d}{D} = \frac{(2 \times 10^{-3})(3 \times 10^{-3})}{1} = 6 \times 10^{-6}\ \text{m}$$

65. (A)(i) Capacitance with dielectric slab

If a dielectric slab of thickness t and dielectric constant K is inserted in a capacitor of plate separation d :

$$C = \frac{\varepsilon_0 A}{(d - t) + \frac{t}{K}}$$

(ii) Capacitors

Given: $V = 100V$

Energy in series:

$$U_s = \frac{1}{2}C_s V^2 \Rightarrow C_s = \frac{2U_s}{V^2} = \frac{2 \times 40 \times 10^{-3}}{(100)^2} = 8 \times 10^{-6}\ \text{F} = 8\mu\ \text{F}$$

Energy in parallel:

$$C_p = \frac{2U_p}{V^2} = \frac{2 \times 250 \times 10^{-3}}{(100)^2} = 50\mu F$$

So:

$$C_1 + C_2 = 50$$

$$\frac{C_1 C_2}{C_1 + C_2} = 8 \Rightarrow C_1 C_2 = 400$$

Solve:

$$x^2 - 50x + 400 = 0$$

$$x = 40, 10$$

OR

(B) (i) Using Gauss's law

For an infinite plane sheet, choose a pillbox Gaussian surface:

$$\Phi = 2EA = \frac{\sigma A}{\varepsilon_0}$$

$$E = \frac{\sigma}{2\varepsilon_0}$$

Direction is normal to the sheet:

$$\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$$

(ii) Given: $\vec{E} = (5x^2 + 2)\hat{\imath}$, cube side $a = 0.1\text{m}$

Only two faces (normal to x-axis) contribute to flux:

$$\Phi = A[E(0.1) - E(0)]$$

$$A = (0.1)^2 = 0.01$$

$$E(0.1) = 2.05, E(0) = 2$$

$$\Phi = 0.01 \times (0.05) = 5 \times 10^{-4}\ \text{N m}^2/\text{C}$$

Flux:

$$5 \times 10^{-4}\ \text{N m}^2/\text{C}$$

Net charge:

$$q = \varepsilon_0 \Phi = 8.85 \times 10^{-12} \times 5 \times 10^{-4} = 4.4 \times 10^{-15}\text{C}$$

Net charge:

$$4.4 \times 10^{-15}\text{C}$$

66. (A) (i) Series LCR Resonance

• Factors: The resonant frequency (f_0) depends only on the Inductance (L) and Capacitance (C). It is independent of Resistance (R).

• Formula: $f_0=\frac{1}{2\pi\sqrt{LC}}$

• Graph: The impedance (Z) is minimum at f_0 (where $Z=R$) and increases on both sides, forming a U-shaped curve.

(ii) Step-Up Transformer

• Diagram:

• Working: It works on the principle of mutual induction. When an alternating current passes through the primary coil, it creates a continuously changing magnetic flux in the soft iron core. This changing flux links with the secondary coil, inducing an electromotive force (EMF).

• Step-up Action: Since the number of turns in the secondary (N_s) is greater than the primary (N_p), the induced output voltage is higher than the input voltage ($V_s>V_p$).

(iii) Energy Losses in a Real Transformer

(1). Copper Loss: Heat generated (I^2R) due to the resistance of the copper wire in the primary and secondary windings.

(2). Eddy Current Loss: Energy lost as heat due to circulating "eddy" currents induced in the solid iron core by the changing magnetic flux. (Minimized by using a laminated core).

OR

(i) AC Generator

Construction:

• Field Magnet: Provides a strong, uniform magnetic field.

• Armature: A coil (ABCD) wound on a soft iron core to increase magnetic flux.

• Slip Rings: Two metal rings (R_1,R_2) that rotate with the coil.

• Brushes: Stationary carbon blocks (B_1,B_2) that collect current from the rings.

Working:

• Principle: Electromagnetic Induction.

• As the armature rotates, the magnetic flux through the coil changes, inducing an EMF.

• The direction of the current reverses every 180° (half-cycle) as the sides of the coil swap their direction of motion relative to the magnetic field, producing Alternating Current (AC).

(ii) Magnetic Moment of a Revolving Electron

For an electron of charge e moving with speed v in an orbit of radius r :

(1). Equivalent Current (I):

The time period of one revolution is $T=\frac{2\pi r}{v}$.

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

(2). Magnetic Moment (M):

The area of the orbit is $A=\pi r^2$.

The magnetic moment is given by:

$$M=I\times A$$

$$M=\left(\frac{ev}{2\pi r}\right)\times(\pi r^2)$$

Final Expression:

$$M=\frac{evr}{2}$$

67. **(c)** For a charged particle in a uniform electric field:

Force: $F=qE$

Acceleration: $a=\frac{qE}{m}$

Starting from rest, distance covered:

$$s=\frac{1}{2}at^2=\frac{1}{2}\cdot\frac{qE}{m}\cdot t^2$$

So,

$t^2\propto m$ (since q,E,s are same)

Hence,

$t\propto\sqrt{m}$

Therefore,

$$\frac{t_P}{t_Q} = \sqrt{\frac{m_P}{m_Q}}$$

68. (a) Drift speed in a conductor is directly proportional to the applied potential difference:

$v_d \propto E \propto V$

So if the potential difference is reduced from V to $\frac{V}{2}$, the drift speed also becomes half:

$$v_d' = \frac{v_d}{2}$$

69. (b) Magnetic moment of a current loop:

$M = IA$

Wire length = circumference of circle:

$$2\pi r = 4.4 \Rightarrow r = \frac{4.4}{2\pi} = \frac{2.2}{\pi}$$

Area of loop:

$$A = \pi r^2 = \pi\left(\frac{2.2}{\pi}\right)^2 = \pi \cdot \frac{4.84}{\pi^2} = \frac{4.84}{\pi} \approx \frac{4.84}{3.14} \approx 1.54\ \text{m}^2$$

Now magnetic moment:

$M = IA = 1.0 \times 1.54 = 1.54\text{Am}^2$

70. (c) Magnetic flux:

$\Phi = \vec{B} \cdot \vec{A} = BA\cos\theta$

or directly:

$\Phi = \vec{B} \cdot (A\hat{n})$

Given:

$\vec{B} = (1.0\hat{\imath} + 0.5\hat{\jmath})\text{mT}$

$\hat{n} = (0.6\hat{\imath} + 0.8\hat{\jmath})$

Radius $r = 10\ \text{cm} = 0.1\ \text{m}$

Area:

$A = \pi r^2 = \pi(0.1)^2 = 0.01\pi m^2$

Step 1: Dot product $\vec{B} \cdot \hat{n}$

$= (1.0)(0.6) + (0.5)(0.8) = 0.6 + 0.4 = 1.0\text{mT}$

So,

$\Phi = A \times 1.0\text{mT} = 0.01\pi \times 10^{-3}$

$\Phi = \pi \times 10^{-5}\ \text{Wb}$

$\Phi = 3.14 \times 10^{-5}\ \text{Wb}$

Convert to micro-weber:

$1\mu Wb = 10^{-6}Wb$

$\Phi = 31.4\mu Wb$

71. (d) In an ideal transformer:

- Voltage changes according to turns ratio → not same
- Current also changes inversely → not same
- Power is conserved:

$P_p = P_s$

- Magnetic flux in the core is common to both coils → same

So, magnetic flux is same in both coils, and power is also same.

72. (b) Given:

- Source voltage $V = 100\sqrt{2}V$
- Resistor and inductor in series
- Voltage across R = voltage across L

In a series R-L circuit, if:

$V_R = V_L$

Then:

$$V = \sqrt{V_R^2 + V_L^2}$$

So:

$V = \sqrt{2V_R^2} = V_R\sqrt{2}$

$V_R = \frac{V}{\sqrt{2}} = \frac{100\sqrt{2}}{\sqrt{2}} = 100 \text{ V}$

Voltmeter reading $= 100$ V

73. (d) EM waves (10 nm)

Wavelength 10 nm lies in X-ray region (about $0.01 - 10$ nm).

74. (c) Cut-off wavelength

Work function:

$\phi = 3.315\text{eV}$

Using:

$\lambda_0 = \frac{hc}{\phi}$

and $hc = 1240\text{eV} \cdot \text{nm}$

$\lambda_0 = \frac{1240}{3.315} \approx 374.4 \text{ nm} \approx 375 \text{ nm}$

75. (b) Wavelength relations in transitions

Given:

- $C \rightarrow B$ gives λ_1
- $B \rightarrow A$ gives λ_2
- $C \rightarrow A$ gives λ_3

Energy relation:

$E_{CA} = E_{CB} + E_{BA}$

Since:

$E = \frac{hc}{\lambda}$

So:

$\frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$

76. (c) Closest approach in α-scattering

At closest approach:

$K = \frac{1}{4\pi\epsilon_0}\frac{(2e)(Ze)}{d}$

So:

$d \propto \frac{1}{K}$

77. (c) n-type Si doping

n-type semiconductor is formed by adding pentavalent impurity (donor atoms like P, As, Sb).

- P (Phosphorus) → 5 valence electrons → donates electrons

78. (b) Reverse bias in p-n junction

In reverse bias:

- Barrier potential increases
- Depletion region widens

79. (a) Assertion (A): True

Photoelectric current increases with increase in intensity (for fixed frequency and accelerating potential) because more photons are incident per second.

Reason (R): True

Higher intensity means more incident photons → more emitted photoelectrons per second → higher photocurrent.

Also, R correctly explains A.

80. (b) Assertion (A): True

Lenz's law ensures that induced current always opposes the change producing it, which prevents creation of energy from nothing. Hence, it is a direct consequence of the law of conservation of energy.

Reason (R): True
In an ideal inductor, there is no resistance, so no electrical energy is dissipated as heat → no power loss.
However, **R** does not explain A. It is a correct statement but unrelated to the logical basis of Lenz's law.
So, Both A and R are true, but R is not the correct explanation of A

81. (a) Given:
Electron and proton enter a magnetic field with the same momentum $\vec{p}$ and $\vec{p} \perp \vec{B}$.
Radius of circular path:
$$r = \frac{p}{qB}$$
Assertion (A)
• Electron and proton have same p, same $|q|$, same B
So:
$$r_e = r_p$$
Assertion is TRUE
Reason (R)
$$r = \frac{mv}{qB}$$
• This is also correct, and using $p = mv$, it becomes:
$$r = \frac{p}{qB}$$
Reason is TRUE

82. (c) Assertion (A): True
Magnifying power of a compound microscope is taken as negative because the final image is inverted with respect to the object.
Reason (R): False
The final image formed by a compound microscope is not erect, it is inverted.

83. Resistivity of a conductor (Definition):
Resistivity (ρ) of a conductor is defined as the resistance offered by a material of unit length and unit cross-sectional area. It is a material property and is independent of the size and shape of the conductor.
Mathematically:
$$\rho = \frac{RA}{l}$$
Dependence of resistivity:
From the relation of electrical conductivity in the free electron model:
$$\rho = \frac{m}{ne^2\tau}$$
where
• $n =$ number density of free electrons
• $\tau =$ relaxation time
• $m =$ mass of electron
• $e =$ charge of electron

(A) Dependence on number density n :
$$\rho \propto \frac{1}{n}$$
So, higher number of free electrons - lower resistivity
(B) Dependence on relaxation time τ :
$$\rho \propto \frac{1}{\tau}$$
So, larger relaxation time - lower resistivity (electrons collide less frequently)

84. (A) Resultant intensity
Let the two waves be:
$$y_1 = a\cos\omega t, y_2 = a\cos(\omega t + \phi)$$
Resultant amplitude:
$$A = 2a\cos\left(\frac{\phi}{2}\right)$$

So intensity $I \propto A^2$:

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

If $I_0 = a^2$, then:

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

OR

(B) Effect on Young's double-slit experiment pattern

(i) Source slit moved closer to plane of slits:

• Fringe width unchanged

• Intensity of fringes increases (more illumination)

(ii) Separation between slits increased:

• Fringe width decreases since

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

• So fringes become closer together (more closely spaced)

85. Use lens maker dependence on surrounding medium:

$\frac{1}{f} \propto \left(\frac{n_{lens}}{n_{medium}} - 1\right)$

So,

$\frac{f_{liquid}}{f_{air}} = \frac{(n_{lens}/1 - 1)}{(n_{lens}/n_{liquid} - 1)}$

Given:

$n_{lens} = 1.52, n_{liquid} = 1.65, f_{air} = 15$ cm

Step 1: Compute factors

Air:

$n_{lens} - 1 = 1.52 - 1 = 0.52$

Liquid:

$\frac{1.52}{1.65} - 1 = 0.9212 - 1 = -0.0788$

Step 2: Ratio

$\frac{f_{liquid}}{15} = \frac{0.52}{-0.0788} \approx -6.60$

$f_{liquid} \approx 15 \times (-6.60) \approx -99$ cm

• The nature of a lens depends on the relative refractive indices of the lens and the surrounding medium:

= Because the refractive index of the liquid (1.65) is greater than that of the lens (1.52), the lens reverses its behaviour.

= The resulting negative focal length confirms it will now act as a diverging lens.

86. Binding energy is calculated using mass defect:

$\Delta m = Zm_p + Nm_n - M_{nucleus}$

For ${}^{12}_{6}C$:

$Z = 6, N = 6$

$\Delta m = 6(1.007825) + 6(1.008665) - 12.000000$

$\Delta m = 6.04695 + 6.05199 - 12 = 12.09894 - 12 = 0.09894u$

Binding energy:

$B.E = \Delta m \times 931.5$

$B.E = 0.09894 \times 931.5 \approx 92.2$MeV

87. The energy gap (band gap) of a semiconductor is the energy difference between the valence band and conduction band.

Key point: Doping does not change the actual band gap of the semiconductor. It only introduces new energy levels within the gap.

(a) Doping with trivalent impurity (p-type)

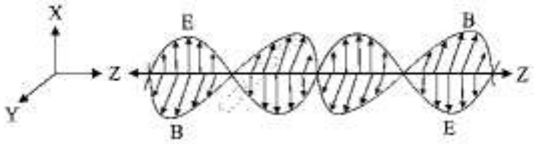
• A trivalent impurity (like B, Al) creates an acceptor level just above the valence band.

• Electrons can easily jump from the valence band to this acceptor level.

Effect:
• The effective energy required for conduction decreases (since electrons need less energy to move).
• But the actual band gap remains unchanged.
Justification: Presence of acceptor level reduces energy needed for excitation.
(b) Doping with pentavalent impurity (n-type)
• A pentavalent impurity (like P, As) introduces a donor level just below the conduction band.
• Electrons can easily move from this donor level to the conduction band.
Effect:
• Effective energy required for conduction decreases.
• The actual band gap remains unchanged.
Justification: Donor level lies close to conduction band, so less energy is needed.
Final conclusion:
In both cases, band gap does not change, but effective energy for conduction decreases due to introduction of impurity levels.

88. Take bottom node $F = D = 0$.
Node equations:
From right branch:
$$\frac{V_C - V_B}{2} + \frac{V_C - 6}{2} = 0 \Rightarrow 2V_C - V_B = 6$$
From node B :
$$\frac{V_B - V_A}{2} + \frac{V_B - V_C}{2} + \frac{V_B - 6}{4} = 0 \Rightarrow 5V_B - 2V_A - 2V_C = 6$$
Left battery:
$V_A - V_G = 3$
Supernode (A & G):
$$\frac{V_A - V_B}{2} + \frac{V_C}{2} = 0 \Rightarrow 2V_A - V_B = 3$$
Solve:
$V_C = 5.5\text{ V}, V_B = 5\text{ V}, V_A = 4\text{ V}$
Currents:
$$I_{AG} = \frac{V_C}{2} = \frac{1}{2} = 0.5\text{ A}(\text{ A} \rightarrow \text{G})$$
$$I_{BF} = \frac{V_B - 6}{4} = -0.25\text{ A} \Rightarrow 0.25\text{ A}(\text{ F} \rightarrow \text{ B})$$
$$I_{CD} = \frac{V_C - 6}{2} = -0.25\text{ A} \Rightarrow 0.25\text{ A}(\text{D} \rightarrow \text{C})$$
$\text{AG} = 0.5\text{ A} \downarrow, \text{BF} = 0.25\text{ A} \uparrow, \text{CD} = 0.25\text{ A} \uparrow$

89. **(A)** The speed of an electromagnetic wave in a medium depends strictly on two fundamental properties of the medium: its absolute electric permittivity (ϵ) and its magnetic permeability (μ). The speed (v) is given by the formula $v = \frac{1}{\sqrt{\mu\epsilon}}$.
(B) An electromagnetic wave is produced by an accelerated or oscillating charged particle. When a charge accelerates, it creates a time-varying electric field, which in turn generates a time-varying magnetic field. This continuous, self-sustaining cycle of mutually regenerating fields propagates through space as an electromagnetic wave.
(C) The following schematic diagram illustrates an electromagnetic wave propagating along the z-axis, with the electric field oscillating along the x-axis and the magnetic field oscillating along the y-axis.



90. Magnetic field inside solenoid:
$B = \mu_0 nI$
Flux through one turn of coil:
$\Phi = B \cdot A = \mu_0 nI \cdot \pi r^2$
Total flux (N turns):

$\Phi_T = N\mu_0 n I \pi r^2$
Induced emf:
$$\mathcal{E} = \frac{d\Phi_T}{dt} = N\mu_0 n\pi r^2 \frac{dI}{dt}$$
Substitute values:
- $N = 100$
- $n = 250$ turns $/\text{cm} = 2.5 \times 10^4\ \text{m}^{-1}$
- $r = 1.6\ \text{cm} = 0.016\ \text{m}$
- $\mu_0 = 4\pi \times 10^{-7}$
- $\frac{dI}{dt} = \frac{1.5}{25\times10^{-s}} = 60$

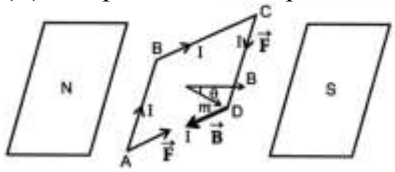
$\mathcal{E} = 100 \cdot 4\pi \times 10^{-7} \cdot 2.5 \times 10^4 \cdot \pi \cdot (0.016)^2 \cdot 60$
Using $\pi^2 = 10$:
$\mathcal{E} = 100 \cdot 4 \times 10^{-7} \cdot 2.5 \times 10^4 \cdot 10 \cdot (0.016)^2 \cdot 60$
$= 100 \cdot (10^{-2}) \cdot 10 \cdot (2.56 \times 10^{-4}) \cdot 60$
$= 100 \cdot 10^{-1} \cdot 2.56 \times 10^{-4} \cdot 60$
$= 10 \cdot 2.56 \times 10^{-4} \cdot 60 = 1.536 \times 10^{-1} = 0.1536\ \text{V}$
Induced current:
$$I = \frac{\mathcal{E}}{R} = \frac{0.1536}{5} \approx 0.03\ \text{A}$$

91. (A) Force between two parallel current-carrying conductors
- When two long parallel conductors carry currents in opposite directions, they repel each other.
- (Same direction → attraction, opposite → repulsion)

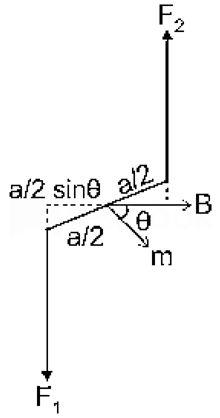
Expression for force
Magnetic field due to wire 1 at distance r :
$$\mathrm{B} = \frac{\mu_0 \mathrm{I}_1}{2\pi \mathrm{r}}$$
Force on length L of wire 2 :
$\mathrm{F} = \mathrm{I}_2\mathrm{LB}$
$$\mathrm{F} = \mathrm{I}_2\mathrm{L} \cdot \frac{\mu_0 \mathrm{I}_1}{2\pi \mathrm{r}}$$
$$\mathrm{F} = \frac{\mu_0 \mathrm{I}_1 \mathrm{I}_2 \mathrm{L}}{2\pi \mathrm{r}}$$
Force per unit length:
$$\frac{\mathrm{F}}{\mathrm{L}} = \frac{\mu_0 \mathrm{I}_1 \mathrm{I}_2}{2\pi \mathrm{r}}$$
Definition of 1 ampere
One ampere is the current which, when flowing through two parallel conductors 1 m apart in vacuum, produces a force of
2×10^{-7} N per meter

OR

(B) The plane of the loop is not along the magnetic field but makes an angle with it.



Let the dimension of the rectangular coil ABCD , be $\mathrm{AB} \times \mathrm{BC} = \mathrm{a} \times \mathrm{b}$
The angle between the field and the normal is θ.
Forces on BC and DA are equal and opposite and they cancel each other as they are collinear.
Force on AB is F_1 and force on CD is F_2.
$\mathrm{F}_1 = \mathrm{F}_2 = \mathrm{IbB}$
The magnitude of the torque on the loop as in the figure:



$\tau = F_1 \frac{a}{2} \sin 0 + F_2 \frac{a}{2} \sin 0$

$= \text{IabB} \sin \theta$

If there are ' n ' such turns the torque will be sin nIabsin θ

The magnetic moment of the current m $=$ IA

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

92. Bohr's postulates used:

(1)Electron revolves in circular orbit under Coulomb force.

(2)Angular momentum is quantized:

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

Derivation

Electrostatic force provides centripetal force:

$\frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} = \frac{mv^2}{r}$ ....(i)

From angular momentum:

$v = \frac{nh}{2\pi mr}$ ....(ii)

Substitute (ii) into (i):

$\frac{1}{4\pi\varepsilon_0} \frac{e^2}{r^2} = \frac{m}{r} \left(\frac{nh}{2\pi mr} \right)^2$

$\frac{1}{4\pi\varepsilon_0} e^2 = \frac{n^2 h^2}{4\pi^2 mr}$

$r = \frac{4\pi\varepsilon_0 n^2 h^2}{4\pi^2 me^2}$

$r_n = \frac{\varepsilon_0 h^2}{\pi me^2} n^2$

Bohr radius (n = 1)

$a_0 = \frac{\varepsilon_0 h^2}{\pi me^2}$

Substituting constants:

$a_0 \approx 5.3 \times 10^{-11}$ m

Answer:

$r_n = n^2 a_0, a_0 = 5.3 \times 10^{-11}$ m

93. Based on the provided graph and the relationship between de Broglie wavelength λ and kinetic energy $\boldsymbol{K}$, here are the answers to the questions:

(A) The de Broglie wavelength is given by the formula:

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

Comparing this to the equation of a straight line ($y = mx$), where $y = \lambda$ and $x = \frac{1}{\sqrt{K}}$, the slope represents $\frac{\mathbf{h}}{\sqrt{\mathbf{2m}}}$.

• Here, $\boldsymbol{h}$ is Planck's constant and $\boldsymbol{m}$ is the mass of the particle.

(B) From the slope formula Slope $= \frac{h}{\sqrt{2m}}$, we can see that the slope is inversely proportional to the square root of the mass (Slope $\propto \frac{1}{\sqrt{m}}$).

• The graph shows that the line for m_2 has a steeper slope than the line for m_1.

• Since a larger slope implies a smaller mass, particle $1(m_1)$ is heavier.

(C) No, this graph is not valid for a photon.

• Justification: The formula $\lambda = \frac{h}{\sqrt{2mK}}$ is derived for particles with non-zero rest mass. For a photon (which is massless and travels at the speed of light), the relationship between energy $\boldsymbol{E}$ and wavelength is $\boldsymbol{E} = \frac{\boldsymbol{hc}}{\boldsymbol{\lambda}}$, or $\lambda = \frac{\boldsymbol{hc}}{\boldsymbol{E}}$.

• Therefore, for a photon, λ is proportional to $\frac{1}{E}$, not $\frac{1}{\sqrt{E}}$.

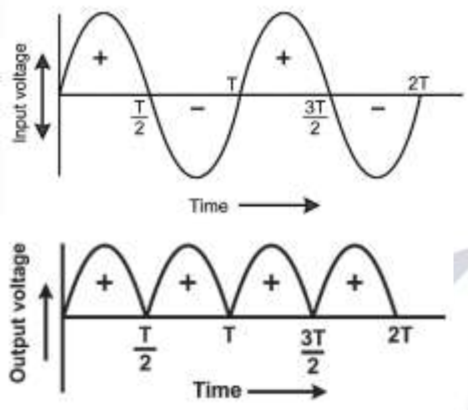
94. Full wave rectifier:

When the diode rectifies the whole of the AC wave, it is called full wave rectifier.

The figure shows the arrangement for using diode as full wave rectifier. The alternating input signal is fed to the primary P_1P_2 of a transformer. The output signal appears across the load resistance R_L.

During the positive half of the input signal, suppose P_1 and P_2 are negative and positive respectively. This would mean that S_1 and S_2 are positive and negative respectively. Therefore, the diode D_1 is forward biased and D_2 is reverse biased. The flow of current in the load resistance R_L is from A to B .

During the negative half of the input signal, S_1 and S_2 are negative and positive respectively. Therefore, the diode D_1 is reverse biased and D_2 is forward biased. The flow of current in the load resistance R_L is from A to B .



95. **(i) (b)**

(ii) (b)

For cells in parallel, equivalent emf:

$$E = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$$

Substitute:

$$E = \frac{\frac{2}{0.1} + \frac{6}{0.4}}{\frac{1}{0.1} + \frac{1}{0.4}} = \frac{20 + 15}{10 + 2.5} = \frac{35}{12.5} = 2.8 \text{ V}$$

(iii) (a)

At open circuit (no current drawn), the emf of the cell is the potential difference between the two electrodes.

Given:

• Positive electrode potential $= V_+$

• Negative electrode potential $= -V_-$

$\varepsilon = V_+ - (-V_-) = V_+ + V_-$

Since both $V_+ > 0$ and $V_- \geq 0$,

$\varepsilon > 0$

(iv)

(A) (d)

Cells in parallel

For identical cells in parallel:
• Equivalent emf $E=2\text{ V}$
• Equivalent internal resistance $r=\frac{0.1}{5}=0.02\Omega$
Total resistance:
$R_{\text{total}}=9.98+0.02=10\Omega$
Current:
$$I=\frac{E}{R}=\frac{2}{10}=0.2\text{ A}$$

OR

(B) (a)
Internal resistance
$V=\varepsilon-Ir$
$4=6-2r\Rightarrow 2r=2\Rightarrow r=1\Omega$

96. **(i) (d)** At critical angle, angle of incidence = angle of reflection (law of reflection).
So, angle of reflection = critical angle ($<90^{\circ}$)

(ii) (d)
Wavelength changes with medium:
$$\lambda\propto\frac{1}{n}$$
From water ($n=4/3$) to air ($n=1$) :
$$\lambda_{\text{air}}=\lambda_{\text{water}}\times\frac{n_{\text{water}}}{n_{\text{air}}}=600\times\frac{4}{3}=800\text{ nm}$$

(iii) (A) (a)
Refracted ray is parallel to the interface $\Rightarrow$ angle of refraction $r=90^{\circ}$
So, angle of incidence = critical angle C
Given: incident ray makes 30° with the surface
$i=90^{\circ}-30^{\circ}=60^{\circ}$
Thus, $C=60^{\circ}$
Using relation:
$$\sin C=\frac{n_B}{n_A}$$
$$\frac{n_B}{n_A}=\sin 60^{\circ}=\frac{\sqrt{3}}{2}$$

OR

(B) (b)
Refractive index $n=\frac{c}{v}$
$$\frac{n_B}{n_A}=\frac{v_A}{v_B}=\frac{2\times10^{8}}{2.5\times10^{8}}=\frac{4}{5}$$
For critical angle:
$$\sin C=\frac{n_B}{n_A}=\frac{4}{5}$$

(iv) (a)
From the figure, the prism angle is 90°, so the ray inside strikes the second face at 45°.
For the ray to just emerge (as shown), this internal incidence equals the critical angle:
$C=45^{\circ}$
Using:
$$\sin C=\frac{1}{n}\Rightarrow \sin 45^{\circ}=\frac{1}{n}\Rightarrow\frac{1}{\sqrt{2}}=\frac{1}{n}\Rightarrow n=\sqrt{2}$$
Now apply Snell's law at first surface:
$\sin\theta=n\sin r$
Here $r=45^{\circ}$:
$$\sin\theta=n\cdot\frac{1}{\sqrt{2}}=\frac{n}{\sqrt{2}}$$
Using $n^2=2$:

$\sin\theta = \sqrt{n^2 - 1}$

97. (A)(i) Potential due to an electric dipole (far field)

For a dipole of moment $\vec{p}$, at a point $\vec{r}$ making angle θ with dipole axis, and $r \gg$ separation:

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$

(ii) Value of n

Potential energy of system:

$$U = \frac{1}{4\pi\varepsilon_0}\left(\frac{q \cdot 2q}{a} + \frac{2q \cdot nq}{a} + \frac{nq \cdot q}{a}\right)$$

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

Given $U = 0$:

$$2 + 3n = 0 \Rightarrow n = -\frac{2}{3}$$

OR

(B) (i) Gauss's Law and Infinite Plane Sheet

Gauss's Law State:

The total electric flux through any closed surface is equal to $\frac{1}{\epsilon_0}$ times the net charge enclosed by that surface:

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enclosed}}}{\epsilon_0}$$

Electric Field near an Infinite Plane Sheet:

(1) Gaussian Surface: Consider a cylindrical pillbox perpendicular to the sheet, with cross-sectional area A.

(2) Flux: The field $\vec{E}$ is perpendicular to the sheet. Flux only passes through the two end caps $(2EA)$. Flux through the curved surface is zero.

(3) Charge Enclosed: If σ is the surface charge density, then $q_{\text{encl}} = \sigma A$.

(4) Applying Gauss's Law:

$$2EA = \frac{\sigma A}{\epsilon_0} \Longrightarrow \mathbf{E} = \frac{\boldsymbol{\sigma}}{2\epsilon_0}$$

(ii) Net Force on an Electron at Point P

(1) Identify Constants and Distances:

- Charge of electron $(e) = -1.6 \times 10^{-19}\text{C}$
- Distance from Wire $1(r_1) = 10\text{ cm} = 0.1\text{ m}$
- Distance from Wire $2(r_2) = 30\text{ cm} - 10\text{ cm} = 20\text{ cm} = 0.2\text{ m}$
- $\lambda_1 = 10 \times 10^{-6}\text{C/m}, \lambda_2 = -20 \times 10^{-6}\text{C/m}$

(2) Calculate Electric Fields at P:

The field due to a long wire is $\boldsymbol{E} = \frac{\lambda}{2\pi\varepsilon_0 r}$.

- $\vec{E}_1$ (from Wire 1): λ_1 is positive, so field points down $(-\hat{j})$.

$$E_1 = \frac{10 \times 10^{-6}}{2\pi\varepsilon_0(0.1)} = \frac{10^{-4}}{2\pi\varepsilon_0} \text{ (Downwards)}$$

- $\vec{E}_2$ (from Wire 2): λ_2 is negative, so field points towards it, which is also down $(-\hat{j})$.

$$E_2 = \frac{20 \times 10^{-6}}{2\pi\epsilon_0(0.2)} = \frac{10^{-4}}{2\pi\epsilon_0} \text{ (Downwards)}$$

(3) Net Electric Field ($\vec{E}_{\text{net}}$):

Both fields point in the $-\hat{j}$ direction:

$$\vec{E}_{\text{net}} = -\left(\frac{10^{-4}}{2\pi\varepsilon_0} + \frac{10^{-4}}{2\pi\varepsilon_0}\right)\hat{j} = -\frac{10^{-4}}{\pi\varepsilon_0}\hat{j} \text{ N/C}$$

(4) Net Force $(\vec{F})$:

$$\vec{F} = q\vec{E}_{net} = (-e)\left(-\frac{10^{-4}}{\pi\epsilon_0}\hat{j}\right) = \frac{e \times 10^{-4}}{\pi\epsilon_0}\hat{j}$$

Using $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$, then $\frac{1}{\pi\varepsilon_0} = 36 \times 10^9$.

$$\vec{F} = (1.6 \times 10^{-19}) \times (10^{-4}) \times (36 \times 10^9)\hat{j}$$

$\vec{F} \approx 5.76 \times 10^{-13}\hat{j}N$

98. (A) (i) Helical Path and Frequency

When a charge q enters a magnetic field $\vec{B}$ at an angle θ :

(1) Velocity Components: The velocity $\vec{v}$ splits into $v_{\|} = v\cos\theta$ (parallel to $\vec{\boldsymbol{B}}$) and $v_{\perp} = v\sin\theta$ (perpendicular to $\vec{B}$).

(2) Motion:

(i) $v_{\perp}$ provides the centripetal force $\left(qv_{\perp}B = \frac{mv_1^2}{r}\right)$, causing circular motion in the y - z plane.

(ii) $v_{\|}$remains constant (no magnetic force parallel to $\vec{B}$), causing linear motion along the x-axis.

(iii) Result: The combination of circular and linear motion results in a helical path.

Frequency (f):

From the circular motion: $r = \frac{mv_1}{qB}$.

The time period $T = \frac{2kr}{v_1} = \frac{2km}{qB}$.

$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

(ii) Magnetic Moment of Electron

Given:

• Radius $(r) = 2Å = 2 \times 10^{-10}$ m

• Frequency $(f) = 8 \times 10^{14}$rev/s(Hz)

• Charge of electron $(e) = 1.6 \times 10^{-19}$C

(1) Current (D): $I = qf = e \times f$

$I = (1.6 \times 10^{-19}) \times (8 \times 10^{14}) = 1.28 \times 10^{-4}$ A

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

$A = \pi \times (2 \times 10^{-10})^2 = 4\pi \times 10^{-20}$ m^2

(3) Magnetic Moment (μ): $\mu = IA$

$\mu = (1.28 \times 10^{-4}) \times (4\pi \times 10^{-20})$

$\mu \approx 1.61 \times 10^{-23}$ A · m^2

OR

(B) (i)

Current sensitivity (S_i):

Deflection per unit current

$$S_i = \frac{\theta}{I} = \frac{nBA}{k}$$

To increase current sensitivity:

• Increase number of turns n

• Increase area A

• Increase magnetic field B

• Decrease torsional constant k

Why higher current sensitivity $\neq$ higher voltage sensitivity:

Voltage sensitivity

$$S_v = \frac{\theta}{V} = \frac{\theta/I}{R} = \frac{S_i}{R}$$

If resistance R increases (often happens while increasing sensitivity), S_v may decrease. Hence not necessarily increased.

(ii)

Given:

$R_g = 15\Omega, I_g = 20$ mA $= 0.02$ A$, V = 100$ V

Series resistance required:

$$R = \frac{V}{I_g} - R_g = \frac{100}{0.02} - 15 = 5000 - 15 = 4985\Omega$$

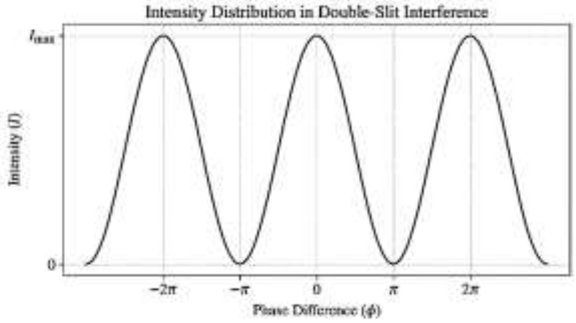
99. (A) (i) Two differences:

• Origin:

Interference → due to superposition of waves from two coherent sources

Diffraction → due to bending of light from different parts of same slit

• Pattern:
Interference → equally spaced bright and dark fringes of equal width
Diffraction → central maximum is widest and brightest; others are unequal and weaker
(ii) Intensity distribution (double slit):
In a double-slit interference pattern, the intensity follows a $\cos^2$ distribution, resulting in equally spaced peaks of equal height, assuming identical slit widths.



(iii)
Intensity in YDSE:

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

Given: for $\Delta = \lambda$

$$I = 4I_0\cos^2(\pi) = 4I_0 = K \Rightarrow I_0 = \frac{K}{4}$$

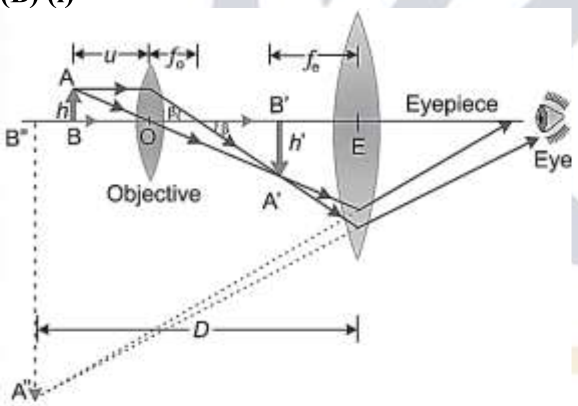
For $\Delta = \frac{\lambda}{6}$:

$$I = 4I_0\cos^2\left(\frac{\pi}{6}\right) = 4I_0 \cdot \left(\frac{\sqrt{3}}{2}\right)^2 = 4I_0 \cdot \frac{3}{4} = 3I_0$$

$$I = 3 \cdot \frac{K}{4} = \frac{3K}{4}$$

OR

(B) (i)



A simple microscope has a limited maximum magnification (≤ 9) for realistic focal lengths. For much larger magnifications, one uses two lenses, one compounding the effect of the other. This is known as a compound microscope. A schematic diagram of a compound microscope is shown in Fig. The lens nearest the object, called the objective, forms a real, inverted, magnified image of the object. This serves as the object for the second lens, the eyepiece, which functions essentially like a simple microscope or magnifier, produces the final image, which is enlarged and virtual. The first inverted image is thus near (at or within) the focal plane of the eyepiece, at a distance appropriate for final image formation at infinity, or a little closer for image formation at the near point. Clearly, the final image is inverted with respect to the original object. We now obtain the magnification due to a compound microscope. The ray diagram of Figure shows that the (linear) magnification due to the objective, namely h'/h, equals

$$m_o = \frac{h'}{h} = \frac{L}{f_o}$$

where we have used the result

$\tan\beta = \left(\frac{h}{f_o}\right) = \left(\frac{h'}{L}\right)$

Here h′ is the size of the first image, the object size being h and fo being the focal length of the objective. The first image is formed near the focal point of the eyepiece. The distance L, i.e., the distance between the second focal point of the objective and the first focal point of the eyepiece (focal length fe) is called the tube length of the compound microscope. As the first inverted image is near the focal point of the eyepiece, we use the result for the simple microscope to obtain the (angular) magnification me due to it equation $m = \left(1 + \frac{D}{f}\right)$, when the final image is formed at the near point, is

$m_e = \left(1 + \frac{D}{f_e}\right)$

When the final image is formed at infinity, the angular magnification due to the eyepiece is

$m_e = (D/fe)$

Thus, the total magnification, when the image is formed at infinity, is

$m = m_a\ m_e = \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$

Clearly, to achieve a large magnification of a small object (hence the name microscope), the objective and eyepiece should have small focal lengths.

(ii) Telescope Magnifying Power Calculation

For a telescope in normal adjustment (final image at infinity), the magnifying power (m) is the ratio of the focal length of the objective to the focal length of the eyepiece.

Given:

• Focal length of objective $(f_o) = 100$ cm

• Focal length of eyepiece $(f_e) = 5$ cm

Formula:

$m = -\frac{f_o}{f_e}$

Calculation:

$m = -\frac{100}{5}$

$m = -20$

100. **(b)** At large distance, a group of charges with $\Sigma q \neq 0$ behaves like a point charge.

Equipotential surfaces of a point charge are spherical.

101. **(b)** Work done on charge $= q(V_2 - V_1)$

Here,

$q = +1.6 \times 10^{-19} C$ (proton)

$V_1 = -5V, V_2 = +5V$

$W = 1.6 \times 10^{-19} \times (5 - (-5)) = 1.6 \times 10^{-19} \times 10$

$W = 1.6 \times 10^{-18}$ J

102. **(c)** Use Biot-Savart law:

$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l} \times \vec{r}}{r^3}$

Here,

• $d\vec{l}$ is along +y direction

• Position vector $\vec{r} = 3\hat{\imath} + 4\hat{\jmath}$

$d\vec{l} \times \vec{r} = \hat{\jmath} \times (3\hat{\imath} + 4\hat{\jmath}) = 3(\hat{\jmath} \times \hat{\imath}) + 4(\hat{\jmath} \times \hat{\jmath}) = 3(-\hat{k}) + 0 = -3\hat{k}$

So direction is $-\hat{k}$.

Magnitude:

$r = \sqrt{3^2 + 4^2} = 5$ m

$B = \frac{10^{-7} \times 5 \times 0.02 \times 3}{5^3} = \frac{3 \times 10^{-8}}{125} = 0.24 \times 10^{-9} T = 0.24 nT$

So, $\vec{B} = -0.24\text{nT}\hat{k}$

103. **(d)** A current-carrying loop in a uniform magnetic field experiences no net force (only possible torque).
Here, magnetic field is along $+z$-axis, and the loop lies in xy-plane → its magnetic moment is also along $\pm z$ axis, so torque is zero as well.
Hence, the loop neither moves nor rotates.

104. **(b)** Potential energy of a magnetic dipole:
$U = -MB\cos\theta$
Initially, plane $\perp \vec{B} \Rightarrow$ magnetic moment $\vec{M} \| \vec{B} \Rightarrow \theta_1 = 0^\circ$
After rotation $45^\circ: \theta_2 = 45^\circ$
Work done:
$W = U_2 - U_1 = -MB(\cos 45^\circ - \cos 0^\circ)$
$W = -MB\left(\frac{1}{\sqrt{2}} - 1\right) = MB\left(1 - \frac{1}{\sqrt{2}}\right)$
$\frac{1}{\sqrt{2}} \approx 0.707$
$\Rightarrow W \approx MB(1 - 0.707) \approx 0.293MB \approx 0.3MB$

105. **(c)** Use the formula of self-induced emf:
$e = L\frac{dI}{dt}$
Given:
$L = 15\text{mH} = 15 \times 10^{-3}\text{H}$
Change in current $\Delta I = 4$ A
Time $\Delta t = 0.004s$
$e = 15 \times 10^{-3} \times \frac{4}{0.004} = 15 \times 10^{-3} \times 1000 = 15V$

106. **(b)** Self-inductance of a solenoid:
$L = \mu_0 \frac{N^2 A}{l}$
With N constant:
- $L \propto A$ (increases with area)
- $L \propto \frac{1}{l}$ (increases when length decreases)

So, L increases when A increases and I decreases.

107. **(b)** In the electromagnetic spectrum, frequency increases as:
Radio waves < Microwaves < Infrared < Visible < UV < X-rays < Gamma rays
So, the highest frequency is Gamma rays.

108. **(b)** For distance of closest approach:
$r = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{\frac{1}{2}mv^2}$
So, $r \propto \frac{q}{m}$ (since target nucleus and velocity are same)
For proton:
$q_p = e, m_p = m$
For alpha particle:
$q_\alpha = 2e, m_\alpha = 4m$
$\frac{r_p}{r_\alpha} = \frac{(e/m)}{(2e/4m)} = \frac{e/m}{e/2m} = 2$

109. **(c)** Photoelectric equation:
$K_{\max} = h\nu - \phi$
This is a straight line with positive slope (**h**) and it cuts the frequency axis at a non-zero threshold frequency (where $K_{\max} = 0$).
So the graph:
- does not pass through origin
- starts from a positive $\boldsymbol{\nu}$-intercept
- increases linearly

110. **(b)** In Bohr model, time period $T \propto n^3$

$$\frac{T_2}{T_1} = \left(\frac{2}{1}\right)^3 = 8$$

So $T_1 = \frac{T_2}{8}$

Decrease $= T_2 - T_1 = T_2 - \frac{T_2}{8} = \frac{7}{8} T_2$

Percentage decrease:

$$\frac{7}{8} \times 100 = 87.5\%$$

111. **(b)** Doping Si with a pentavalent element forms an $\boldsymbol{n}$-type semiconductor. The extra electron is loosely bound and requires very small energy ($\sim 0.01 - 0.05\mathrm{eV}$) to become free.

Typical value $\approx 0.05\mathrm{eV}$

112. **(d)** Assertion (A): False - In a semiconductor, electrons in the conduction band have higher energy than those in the valence band.

Reason (R): False - Donor energy level lies just below the conduction band, not above the valence band.

113. **(c)** Assertion (A): True - Photoelectric effect shows particle nature of light.

Reason (R): False - Photoelectric current depends on intensity, not frequency (frequency affects kinetic energy).

114. **(b)**

115. **(a)** A convex lens "disappears" in a liquid only when there is no refraction at its surfaces, i.e., when both have the same refractive index.

Lens formula (in a medium):

$$\frac{1}{f} = \left(\frac{n_{\text{lens}}}{n_{\text{medium}}} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

If $n_{\text{lens}} = n_{\text{medium}}$, then

$$\frac{n_{\text{lens}}}{n_{\text{medium}}} - 1 = 0 \Rightarrow \frac{1}{f} = 0 \Rightarrow f = \infty$$

So, the lens has no focusing power and becomes invisible (disappears).

Assertion (A): True

Reason (R): True

116. **(A)** Relaxation Time & Resistance Derivation

Relaxation time (τ) :

It is the average time between two successive collisions of a free electron with the ions of the conductor.

Using drift velocity:

$$v_d = \frac{eE\tau}{m}$$

Current:

$$I = neAv_d$$

Substitute v_d :

$$I = neA \cdot \frac{eE\tau}{m} = \frac{ne^2A\tau}{m} E$$

But $E = \frac{V}{l}$, so:

$$I = \frac{ne^2A\tau}{m} \cdot \frac{V}{l}$$

$$\Rightarrow \frac{V}{I} = \frac{ml}{ne^2\tau A}$$

$$R = \frac{ml}{ne^2\tau A}$$

OR

(B) Wheatstone Bridge

Condition for no current through galvanometer (balanced bridge):

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

At this condition, potential difference across galvanometer $= 0$, so no current flows.

117. For an astronomical telescope in normal adjustment:

$M=\frac{f_o}{f_e}, L=f_o+f_e$

Given:

$M=24, L=150 \text{ cm}$

So,

$f_o=24 f_e$

Substitute in L :

$24 f_e+f_e=150 \Rightarrow 25 f_e=150 \Rightarrow f_e=6 \text{ cm}$

$f_o=24 \times 6=144 \text{ cm}$

118. **(A)**In a simple microscope, the angular size of the object equals the angular size of the image because the image formed is virtual, erect, and of the same size as the object. However, the microscope offers magnification because it allows the object to be placed closer to the eye than the near point, thereby increasing the angular size of the object as seen by the eye.

(B) Both plane and convex mirrors typically produce virtual images because the reflected rays diverge and appear to come from a point behind the mirror. However, they can produce real images if the object is virtual. For instance, if a virtual object is placed in front of a convex mirror, the reflected rays can converge to form a real image. For question 20: The minimum intensity of white light that our eyes can perceive is given as 0.1nWm^{-2}. The area of the pupil is $0.4 \text{ cm}^2=0.4 \times 10^{-4} \text{ m}^2$. The energy per second entering the pupil is $I \times A=0.1 \times 10^{-9} \times 0.4 \times 10^{-4}=4 \times 10^{-15}$ W. The energy of one photon is $E=\frac{h c}{\lambda}$, where $h=6.6 \times 10^{-34} \text{Js}, c=3 \times 10^8 \text{ m/s}$, and $\lambda=500 \text{ nm}=500 \times 10^{-9}$ m. Thus, $E=\frac{6.6 \times 10^{-34} \times 3 \times 10^8}{500 \times 10^{-9}}=3.96 \times 10^{-19}$ J. The number of photons per second is $\frac{4 \times 10^{-15}}{3.96 \times 10^{-19}} \approx 10^4$.

119. Given:

Intensity $I=0.1 \text{nW/m}^2=1 \times 10^{-10} \text{ W/m}^2$

Area $A=0.4 \text{ cm}^2=4 \times 10^{-5} \text{ m}^2$

Wavelength $\lambda=500 \text{ nm}=5 \times 10^{-7} \text{ m}$

$h=6.6 \times 10^{-34} \text{Js}, c=3 \times 10^8 \text{ m/s}$

Energy per photon:

$$E=\frac{h c}{\lambda}=\frac{6.6 \times 10^{-34} \times 3 \times 10^8}{5 \times 10^{-7}}=3.96 \times 10^{-19} \text{ J}$$

Power entering eye:

$P=I A=(1 \times 10^{-10})(4 \times 10^{-5})=4 \times 10^{-15} \text{ W}$

Number of photons per second:

$$n=\frac{P}{E}=\frac{4 \times 10^{-15}}{3.96 \times 10^{-19}} \approx 1 \times 10^4$$

120. Given:

Number of Si atoms $=5 \times 10^{28} \text{ m}^{-3}$

Doping $=1 \text{ppm}=10^{-6}$

Acceptor concentration (Boron):

$N_A=5 \times 10^{28} \times 10^{-6}=5 \times 10^{22} \text{ m}^{-3}$

Since it is p-type doping:

$p \approx N_A=5 \times 10^{22} \text{ m}^{-3}$

Using:

$n p=n_i^2$

$$n=\frac{n_i^2}{p}=\frac{(1.5 \times 10^{16})^2}{5 \times 10^{22}}=\frac{2.25 \times 10^{32}}{5 \times 10^{22}}=4.5 \times 10^9 \text{ m}^{-3}$$

Hole concentration: $p=5 \times 10^{22} \text{ m}^{-3}$

Electron concentration: $n=4.5 \times 10^9 \text{ m}^{-3}$

121. (1).Circuit Analysis & Symmetry

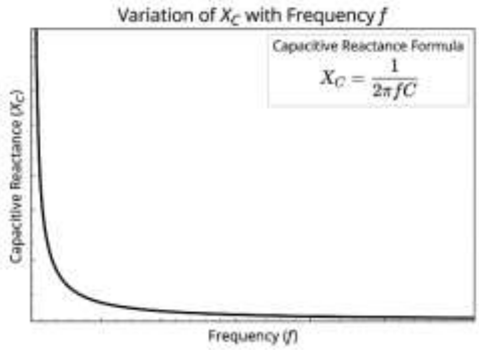
The circuit is symmetric about the horizontal line passing through A, C, and F .

• Let the current in AB be I_1. Due to symmetry, the current in AD is also I_1.

• Let the current in BC be I_2. Due to symmetry, the current in DC is also I_2.
• The current in BF (and DF) is ($I_1 - I_2$) by Kirchhoff's Current Law (KCL) at node B.
(2).Applying Kirchhoff's Voltage Law (KVL)
Loop 1: ABCA (Starting from A , through B and C , back to A)
$-4I_1 - 2I_2 + 1(I_{AC}) + 10 = 0$
From KCL at node C , the total current entering C is $2I_2$ (from B and D). This current must flow through the central branch towards A. So, $I_{AC} = 2I_2$.
$-4I_1 - 2I_2 + 2I_2 + 10 = 0 \Longrightarrow 4I_1 = 10 \Longrightarrow I_1 = 2.5$ A
Loop 2: BFCB (Outer right loop)
Moving from B → F → C → B :
$5 - 2I_2 = 0 \Longrightarrow 2I_2 = 5 \Longrightarrow I_2 = 2.5$ A
(Note: There is no resistance in branch BF, so the potential difference $V_B - V_F = 0$, making $V_B = V_F$ The $5V$ battery is directly across branch BC/DC).
(3). Final Results
• Current in AB($\boldsymbol{I_1}$): 2.5 A
• Current in BC($\boldsymbol{I_2}$): 2.5 A
• Current in AC($2I_2$): 5.0 A

122. A current-carrying conductor produces a magnetic field. When another conductor carrying current is plac in this field, it experiences a magnetic force due to interaction between the field and moving charges.
Derivation (force per unit length):
Magnetic field at distance d from first conductor carrying current I_1 :
$$B = \frac{\mu_0 I_1}{2\pi d}$$
Force on length L of second conductor carrying current I_2 :
$$F = I_2 LB$$
Substitute B :
$$F = I_2 L \cdot \frac{\mu_0 I_1}{2\pi d}$$
$$F = \frac{\mu_0 I_1 I_2 L}{2\pi d}$$
Force per unit length:
$$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d}$$
Nature of force:
• Same direction currents → Attractive force
• Opposite direction currents → Repulsive force

123. **(A)** Circuit element:
X is a capacitor.
(B) Reactance formula:
$$X_C = \frac{1}{\omega C}$$
(also $X_C = \frac{1}{2\pi f C}$)
(C) Graph (variation with frequency):



• $X_C \propto \frac{1}{f}$

• Graph is a decreasing rectangular hyperbola:
• High X_C at low frequency
• Low X_C at high frequency
(D) Behaviour:
(i) In AC circuit:
• Offers opposition to current (capacitive reactance)
• Current leads voltage by 90°
• More frequency → less opposition
(ii) In DC circuit:
• Initially allows current (charging)
• After fully charged → acts as open circuit (no current flows)

124. Given:

$\vec{E} = (6.3)\cos(1.5y + 4.5 \times 10^8 t)\hat{\imath}$

So, Wave number $k = 1.5\text{rad/m}$, angular frequency $\omega = 4.5 \times 10^8 \text{rad/s}$

(A) Wavelength & Frequency

$$\lambda = \frac{2\pi}{k} = \frac{2\pi}{1.5} \approx 4.19 \text{ m}$$

$$f = \frac{\omega}{2\pi} = \frac{4.5 \times 10^8}{2\pi} \approx 7.16 \times 10^7 \text{ Hz}$$

(B) Magnetic field amplitude

$$B_0 = \frac{E_0}{c} = \frac{6.3}{3 \times 10^8} = 2.1 \times 10^{-8} \text{ T}$$

(C) Magnetic field expression

Direction:

$\vec{E} \| \hat{\imath}$, propagation along $-\hat{y} \Rightarrow \vec{B} \| \hat{k}$

$\vec{B} = (2.1 \times 10^{-8})\cos(1.5y + 4.5 \times 10^8 t)\hat{k}$

125. Bohr's postulates:

(1) First postulate (stationary orbits):

An electron revolves around the nucleus only in certain permitted circular orbits without radiating energy. These are called stationary states.

(2) Second postulate (quantisation of angular momentum):

$$\text{mvr} = \frac{\text{nh}}{2\text{x}}$$

Derivation of radius of n^{th} orbit

Electrostatic force provides centripetal force:

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

$$\Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} = mv^2$$

From Bohr's second postulate:

$$v = \frac{nh}{2\pi mr}$$

Substitute v into above:

$$\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} = m\left(\frac{nh}{2\pi mr}\right)^2$$

$$\Rightarrow \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} = \frac{n^2h^2}{4\pi^2 mr^2}$$

Solving for r :

$$r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2}$$

Final result:

$$r_n = n^2 a_0$$

where

$$a_0 = 0.53\text{Å} \text{ (Bohr radius)}$$

Hence, radius $\propto n^2$.

126. **(A)** The atomic mass unit (u) is defined as exactly $\frac{1}{12}$ th of the mass of one atom of carbon-12 (^{12}C).

(B) To find the energy required (binding energy), we first calculate the mass defect (Δm) and then convert it to energy

(1).Mass of constituents:

Mass of proton $(m_H) +$ Mass of neutron (m_n)

$= 1.007825u + 1.008665u = 2.016490u$

(2).Mass defect (Δm):

$\Delta m =$ (Mass of constituents) $-$ Mass of deuteron

$\Delta m = 2.016490u - 2.014102u = 0.002388u$

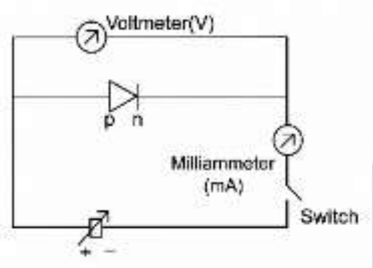
(3).Energy equivalent:

Using the conversion $1u = 931.5MeV$

$E = 0.002388 \times 931.5MeV \approx 2.224MeV$

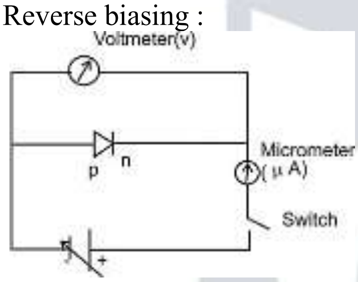
The energy required to separate a deuteron is approximately 2.224 MeV.

127. Forward biasing :

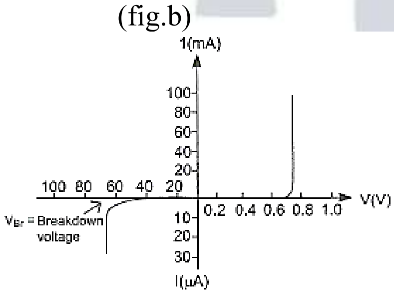


(fig.a)

Reverse biasing :



(fig.b)



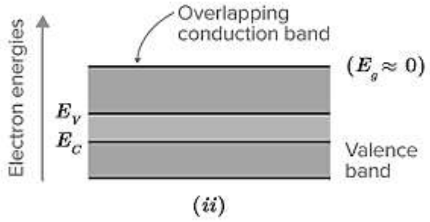
(fig.c)

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

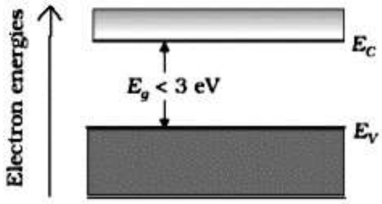
It is evident from a junction diode's V-I characteristics that current can only flow through it when it is forward biassed. As a result, when alternating voltage is placed across a forward biassed diode, current only flows during a portion of the cycle. Alternating voltages are rectified using this characteristic.

OR

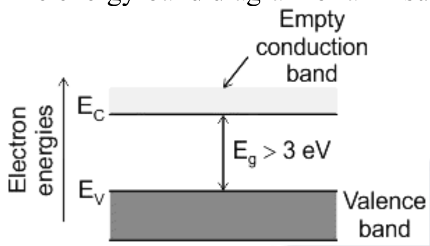
(B) The energy-band diagram of a conductor is represented as



The energy-band diagram of a semiconductor is represented as



The energy-band diagram of an insulator is represented as



128. (i) (d)

(ii) (d)

An electron is negatively charged, so it moves opposite to the direction of the electric field.
In pair IV, the electric field is along $+\hat{\imath}$ direction ⇒ force on electron is along $-\hat{\imath}$ direction.
Also, since force is present, it will accelerate (not move at constant speed).

(iii) (a)

Between two parallel plates, the electric field is uniform, so potential varies linearly with distance.
Using the relation $E = -\frac{dV}{dx}$, a constant electric field implies V is a linear function of x.

$V = V_0 + \alpha x$

(iv) (A) (c)

Between parallel plates, electric field magnitude is

$$E = \frac{\Delta V}{d}$$

So, smaller plate separation ⇒ stronger field (for same potential difference).
From the given plate configurations (I to IV), the spacing decreases in order:

$d_1 > d_2 > d_3 > d_4$

Hence,

$E_1 < E_2 < E_3 < E_4$

OR

(B) (b)

Use energy conservation:
Electron just comes to rest ⇒ initial kinetic energy = electric potential energy gained

$$\frac{1}{2}mv^2 = e\Delta V$$

So,

$$v = \sqrt{2\left(\frac{e}{m}\right)\Delta V}$$

$$v = \sqrt{2\left(\frac{e}{m}\right)\Delta V}$$

For set I, potential difference $\Delta V = 10$ V (from the figure),

$$v = \sqrt{2 \times 1.76 \times 10^{11} \times 10} \approx \sqrt{3.52 \times 10^{12}} \approx 1.9 \times 10^6 \text{ m/s}$$

129. **(i) (d)** In a double-slit with diffraction envelope:

Number of interference fringes within the central diffraction maximum is

$$N=\frac{2d}{a}$$

(where d = slit separation, a = slit width)

$$N=\frac{2d}{a}$$

From the given setup (ratio $d:a=3:1$):

$N=2\times3=6$

(ii) (b) Number of interference maxima within the central diffraction envelope is:

$$N=\frac{2d}{a}-1$$

$$N=\frac{2d}{a}-1$$

If slit width is doubled $\Rightarrow a\rightarrow2a$

$$N'=\frac{2d}{2a}-1=\frac{d}{a}-1$$

Given earlier $\frac{d}{a}=3$:

$N'=3-1=2$

(iii) (A) (c) The number of interference maxima within the central diffraction envelope is:

$$N=\frac{2d}{a}-1$$

$$N=\frac{2d}{a}-1$$

This depends only on $\frac{d}{a}$, not on wavelength.

So changing from 450 nm to 680 nm does not change the number of peaks.

From earlier: $\frac{d}{a}=3$

$N=2(3)-1=5$

Number of peaks (including symmetric counting used in options) $\Longrightarrow 6$

(B) (b) For single slit diffraction, the condition for minima is:

$a\sin\theta=m\lambda$

For the first minimum, $m=1$, so:

$a\sin\theta=\lambda$

$a\sin\theta=\lambda$

So,

$$\sin\theta=\frac{\lambda}{a}$$

From the given case study values (slit width a and wavelength λ), the ratio comes out to approximately:

$\sin\theta\approx0.225$

Thus,

$\theta=\sin^{-1}(0.225)$

(iv) (c) For Young's double slit interference, fringe width is:

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

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

Step 1: Use given data (from case study)

• Screen length $L=1$ m

• Distance $D=\frac{4}{3}$ m

• From case study: fringe width comes out such that $\beta=0.2$ m

Step 2: Number of bright fringes

$$N=\frac{L}{\beta}$$

$$N = \frac{L}{\beta}$$

$$N = \frac{1}{0.2} = 5$$

Step 3: Matching with options

Closest valid option (standard YDSE counting in MCQs gives nearest integer multiple):

130. **(A)(i)** Capacitance of parallel plate capacitor with dielectric

For a parallel plate capacitor:

• Plate area $= A$

• Separation $= d$

• Dielectric constant $= K$

Electric field in dielectric:

$$E = \frac{\sigma}{K\varepsilon_0}$$

Potential difference:

$$V = Ed = \frac{\sigma d}{K\varepsilon_0}$$

But $\sigma = \frac{Q}{A}$, so:

$$V = \frac{Qd}{K\varepsilon_0 A}$$

Capacitance:

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

So,

$$C = \frac{K\varepsilon_0 A}{d}$$

$$C = \frac{K\varepsilon_0 A}{d}$$

(ii) Hollow metallic sphere

Given:

• $Q = 6\mu C = 6 \times 10^{-6} C$

• $R = 0.2m$

• $k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$

(a) Potential at surface

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

$$V = \frac{9 \times 10^9 \times 6 \times 10^{-6}}{0.2}$$

$$V = \frac{54 \times 10^3}{0.2} = 2.7 \times 10^5 V$$

(b) Potential at centre

For a conducting hollow sphere:

• Electric field inside $= 0$

• Potential is constant throughout

So,

$$V_{\text{centre}} = V_{\text{surface}} = 2.7 \times 10^5 \text{ V}$$

OR

(B)(i) Electric field of a charged conducting spherical shell using Gauss's law Let a charge $+Q$ be placed on a thin conducting spherical shell of radius R.

Using Gauss's law.

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{endure}}}{\varepsilon_n}$$

(a) Inside the shell $(r < R)$

Choose a Gaussian sphere of radius $r < R$.

• Charge enclosed = 0 (all charge is on surface)
So,
$E \cdot 4\pi r^2 = 0 \Rightarrow E = 0$
$E_{\text{inside}} = 0$
(b) Outside the shell $(r > R)$
Choose Gaussian surface of radius r.
• Enclosed charge $= Q$
$$E \cdot 4\pi r^2 = \frac{Q}{\varepsilon_0}$$
So,
$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$
$$E_{\text{outside}} = \frac{kQ}{r^2}$$
(ii) Field of sheet
• Non-conducting sheet:
$$E = \frac{\sigma}{2\varepsilon_0}$$
$$E = \frac{\sigma}{2\varepsilon_0}$$
• Conducting sheet:
$$E = \frac{\sigma}{\varepsilon_0}$$
$$E = \frac{\sigma}{\varepsilon_0}$$
Conclusion:
$$E_{\text{conductor}} = 2E_{\text{non-conductor}}$$

131. **(A) (I) (1)** Current sensitivity
Current sensitivity = deflection per unit current:
$$S = \frac{\theta}{I}$$
$$S = \frac{\theta}{I}$$
Depends on: number of turns (N), magnetic field (B), area (A), torsional constant (k)
$$S \propto \frac{NBA}{k}$$
(2) Galvanometer → voltmeter
For range $0 \rightarrow V$:
$$R = \frac{V}{I_s} - G \Rightarrow \frac{V}{I_s} = R + G$$
For range $0 \rightarrow \frac{V}{2}$:
$$R' = \frac{V}{2I_g} - G = \frac{R+G}{2} - G$$
$$R' = \frac{R-G}{2}$$
(II) Induced current
$$\phi = (2t^3 + 5t^2 + 6t)\text{mWb}$$
$$e = \frac{d\phi}{dt} = (6t^2 + 10t + 6)$$
At t = 2 :
$$e = 50\text{mWb/s} = 0.05\ \text{V}$$
Current:
$$I = \frac{e}{R} = \frac{0.05}{5} = 0.01\ \text{A}$$

OR

(B)(i) EMF induced in rotating coil
Magnetic flux:
$\Phi = NBA\cos\theta = NBA\cos(\omega t)$
$\Phi = NBA\cos(\omega t)$
Induced emf:
$$e = -\frac{d\Phi}{dt} = NBA\omega\sin(\omega t)$$
$e = NBA\omega\sin(\omega t)$
(ii) Mutual inductance of two concentric loops
Given:
- $r_1 = 1cm = 0.01m$
- $r_2 = 100cm = 1m$

Magnetic field at center of big loop:
$$B = \frac{\mu_0 I}{2R}$$
Flux through small loop:
$$\Phi = B \cdot A_1 = \frac{\mu_0 I}{2r_2} \cdot \pi r_1^2$$
Mutual inductance:
$$M = \frac{\Phi}{I} = \frac{\mu_0 \pi r_1^2}{2r_2}$$
Substitute values:
- $\mu_0 = 4\pi \times 10^{-7}$
- $\pi^2 = 10$

$$M = \frac{4\pi \times 10^{-7} \cdot \pi(10^{-2})^2}{2 \cdot 1}$$
$M = 2\pi^2 \times 10^{-11}$
Using $\pi^2 = 10$:
$M = 2 \times 10 \times 10^{-11} = 2 \times 10^{-10} H$

132. **(A) (i)** Prism
Angle of deviation:
$\delta = i + e - A$
$\delta = i + e - A$
Graph: δ vs i → U-shaped curve with minimum deviation (δmin).
(ii) Refractive index
Emergent ray along face ⇒ $e = 90°$
Using Snell's law:
$$\mu = \frac{1}{\sin 45°} = \sqrt{2}$$
$\mu = \sqrt{2}\mu \approx 1.41$

OR

(B) (i) Resultant intensity
Given:
$y_1 = a\cos\omega t, y_2 = a\cos(\omega t + \phi)$
Resultant amplitude:
$$R = 2a\cos\left(\frac{\phi}{2}\right)$$
So intensity $I \propto R^2$:
$$I = 4a^2\cos^2\left(\frac{\phi}{2}\right)$$
$$I = 4a^2\cos^2\left(\frac{\phi}{2}\right)$$
(ii) Intensity ratios in YDSE
Intensity:

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

and

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

(a) Path difference $\lambda/6$

$\phi = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{6} = \frac{\pi}{3}$

$I_1 \propto \cos^2\left(\frac{\pi}{6}\right) = \left(\frac{\sqrt{3}}{2}\right)^2 = \frac{3}{4}$

(b) Path difference $\lambda/12$

$\phi = \frac{2\pi}{12} = \frac{\pi}{6}$

$I_2 \propto \cos^2\left(\frac{\pi}{12}\right)$

So ratio:

$I_1 : I_2 = \frac{3}{4} : \cos^2\left(\frac{\pi}{12}\right)$

Using $\cos^2(\pi/12) \approx 0.93$:

$I_1 : I_2 \approx 0.75 : 0.93 \approx 5 : 6$

133. **(b)**For a uniformly charged circular ring, every small charge element has an opposite element producing an equal and opposite electric field at the center.

Hence, all fields cancel out.

134. **(d)** For capacitors in parallel:

Total capacitance $C_{\text{eq}} = 10 \times 1\mu F = 10\mu F = 10 \times 10^{-6} F$

Energy stored:

$U = \frac{1}{2} C V^2$

$U = \frac{1}{2} \times (10 \times 10^{-6}) \times (100)^2$

$U = \frac{1}{2} \times 10 \times 10^{-6} \times 10^4 = \frac{1}{2} \times 10 \times 10^{-2} = 5 \times 10^{-2} J$

135. **(b)** The potential difference between A and B(V_{AB}) is the equivalent EMF of the two parallel branches.

Formula

The equivalent potential difference for two cells in parallel is:

$V_{AB} = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$

Step-by-Step Calculation

• Branch 1: $E_1 = 12 \text{ V}, r_1 = 1\Omega$

• Branch 2: $E_2 = 6 \text{ V}, r_2 = 0.5\Omega$

• Calculation:

$V_{AB} = \frac{\frac{12}{1} + \frac{6}{0.5}}{\frac{1}{1} + \frac{1}{0.5}} = \frac{12 + 12}{1 + 2} = \frac{24}{3} = 8 \text{ V}$

136. **(b)**A current loop in a uniform magnetic field experiences no net force, but each element feels a force directed towards the center → loop shrinks.

137. **(b)** Given:

$\vec{L} = 0.1\hat{\jmath}, \vec{B} = 5 \times 10^{-3}\hat{\jmath} - 8 \times 10^{-3}\hat{k}$

Force:

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

$\vec{L} \times \vec{B} = 0.1\hat{\jmath} \times (5 \times 10^{-3}\hat{\jmath} - 8 \times 10^{-3}\hat{k})$

$= 0 - 0.1 \times 8 \times 10^{-3}(\hat{\jmath} \times \hat{k}) = -0.8 \times 10^{-3}\hat{\imath}$

$\vec{F} = -0.8\text{mN}\hat{\imath}$

138. **(b)** Given galvanometer current $= 0.1\% = 0.001 I_A$

Remaining current through shunt $= 0.999 I_A$

$$R_{\text{ammeter}} = \frac{G}{1+\frac{I_s}{I_\theta}} = \frac{G}{1+999} = \frac{G}{1000}$$

139. **(a)** Reactance:

$$X = \frac{1}{\omega C}$$

New:

$$X' = \frac{1}{(3\omega)(2C)} = \frac{1}{6\omega C} = \frac{X}{6}$$

140. **(a)** Displacement current exists when electric field changes with time.

Only Region I has time dependence $\sin(kz - \omega t)$.

141. **(c)** Balmer series: transitions to $n_f = 2$

Second line: $n_i = 4 \rightarrow n_f = 2$

142. **(b)** As (pentavalent) doping → n-type semiconductor → more free electrons

143. **(c)** Kinetic energy:

$K = E - \phi$

For A: $K_A = 3.3 - 2.3 = 1\text{eV}$

For B: $K_B = 11.3 - 2.3 = 9e\text{ V}$

$$\frac{v_A}{v_B} = \sqrt{\frac{K_A}{K_B}} = \sqrt{\frac{1}{9}} = \frac{1}{3}$$

144. **(a)**From de Broglie relation:

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

Same wavelength ⇒ same momentum

145. **(d)**• Assertion (A): False → In Photoelectric Effect, kinetic energy depends on frequency, not intensity.

• Reason (R): False → Photoelectric current depends mainly on intensity, not wavelength (though wavelength affects emission threshold).

So, Assertion (A) is false and Reason (R) is also false.

146. **(a)**• Assertion (A): True

• Reason (R): True

When two coils are wound on each other, the magnetic flux produced by one links almost completely with the other, making flux linkage maximum → mutual inductance maximum.

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

147. **(a)** Both the Assertion and Reason are correct, and the Reason is the correct explanation for the Assertion.

• Assertion (A): When wires are connected in series, the current flows through the first wire and returns through the second in the opposite direction.

• Reason (R): Magnetic fields produced by anti-parallel currents (opposite directions) create a repulsive force, causing the wires to move apart.

148. **(d)** Assertion (A): False

A convex mirror can form a real image if the object is virtual (i.e., incident rays are converging).

Reason (R): False

A virtual image can act as an object and can produce a real image.

So, Both Assertion and Reason are false.

149. Use the relation for resistance with temperature:

$R = R_0(1 + \alpha\Delta T)$

Given:

$R = 2R_0, \alpha = 4.0 \times 10^{-3}\ \text{K}^{-1}$, reference at 20°C

$2R_0 = R_0(1 + \alpha\Delta T)$

$2 = 1 + \alpha\Delta T$
$\alpha\Delta T = 1$
$\Delta T = \frac{1}{4.0 \times 10^{-3}} = 250°\text{C}$
Final temperature:
$T = 20 + 250 = 270°\text{C}$

150. **(A)** Wavelength in reflection and refraction
Given:
Frequency $f = 5.0 \times 10^{14}$ Hz, refractive index $n = 1.5$
First, wavelength in air:
$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{5.0 \times 10^{14}} = 6.0 \times 10^{-7}$ m
• Reflected light:
Reflection occurs in the same medium (air), so wavelength remains unchanged:
$\lambda_{\text{reflested}} = 6.0 \times 10^{-7}$ml
• Refracted light:
$\lambda_{\text{refracted}} = \frac{\lambda}{n} = \frac{6.0 \times 10^{-7}}{1.5} = 4.0 \times 10^{-7}$ m

OR

(B) Radius of curvature of plano-convex lens
Lens maker formula:
$\frac{1}{f} = (n-1)\left(\frac{1}{R}\right)$
$\frac{1}{f} = (n-1)\frac{1}{R}$
Given: $f = 16$ cm, $n = 1.4$
$\frac{1}{16} = (1.4 - 1)\frac{1}{R}$
$\frac{1}{16} = 0.4 \cdot \frac{1}{R}$
$R = 0.4 \times 16 = 6.4$ cm

151. Given:
Object distance $u = -30$ cm (in front of mirror)
Radius $R = 40$ cm $\Rightarrow f = \frac{R}{2} = -20$ cm
Using mirror formula:
$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$
$\frac{1}{20} = \frac{1}{v} + \frac{1}{30}$
$\frac{1}{v} = -\frac{1}{20} + \frac{1}{30} = \frac{3+2}{60} = -\frac{1}{60}$
$v = -60$ cm
(i) Position of image
$v = -60$ cm
(ii) Magnification
$m = \frac{-v}{u} = \frac{-(-60)}{-30} = -2$
$m = -2$

152. For neutron (non-relativistic):
$E = \frac{p^2}{2m} \Rightarrow p = \sqrt{2mE}$
De Broglie wavelength:
$\lambda_n = \frac{h}{p} = \frac{h}{\sqrt{2mE}}$

For photon:

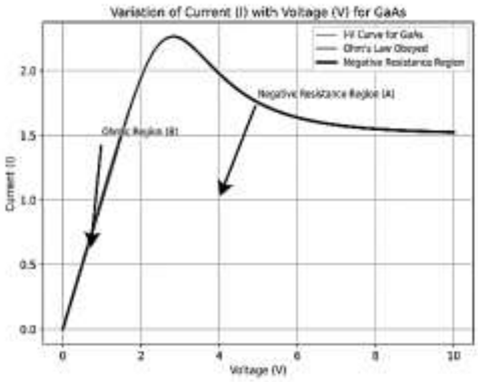
$$E=\frac{hc}{\lambda_p}\Rightarrow\lambda_p=\frac{hc}{E}$$

Now ratio:

$$\frac{\lambda_n}{\lambda_p}=\frac{\frac{h}{\sqrt{2mE}}}{\frac{hc}{E}}=\frac{E}{c\sqrt{2mE}}=\frac{\sqrt{E}}{c\sqrt{2m}}$$

$$\frac{\lambda_n}{\lambda_p}=\sqrt{\frac{E}{2mc^2}}$$

153.



Gallium Arsenide (GaAs) is a semiconductor that exhibits non-linear $I-V$ characteristics, notably featuring a Negative Differential Resistance (NDR) region. This occurs because, at higher electric fields, electrons are transferred from a high-mobility valley to a low-mobility satellite valley in the conduction band.

Below is the graph showing the variation of current with voltage for GaAs:

Analysis of the Regions

(1) Region (B): Ohm's Law is Obeyed

• This is the initial linear portion of the graph (marked in green).

• In this region, the current I is directly proportional to the voltage V. The slope $\left(\frac{\Delta I}{\Delta V}\right)$ is positive and constant, meaning the resistance is positive and stable.

(2) Region (A): Negative Resistance Region

• This is the portion of the curve where the current decreases as the voltage increases (marked in red).

• Mathematically, the differential resistance $r=\frac{dV}{dI}$ is negative because the slope of the $I-V$ graph is negative.

This unique property is utilized in devices like Gunn diodes to generate microwave oscillations.

Key Observation:

Unlike a simple metallic conductor, GaAs does not have a single unique value of current for every voltage across the entire range, and it clearly deviates from Ohm's law once the threshold voltage is reached.

154. **(A)** Calculate the Flux Passing Through the Cube

First, identify the positions of the two faces along the x-axis:

• Left face: $x=0.1\ \mathrm{m}$

• Right face: $x=0.1\ \mathrm{m}+0.1\ \mathrm{m}=0.2\ \mathrm{m}$

• Area (A) of each face: $(0.1\ \mathrm{m})^2=0.01\ \mathrm{m}^2$

Now, calculate the flux for each:

(1) Left Face Flux (Φ_L):

(i) Electric field $E_L=500(0.1)=50\ \mathrm{N/C}$

(ii) The area vector points left (outward), so the angle is 180°.

(iii) $\Phi_L=E_L\cdot A\cdot\cos(180^\circ)=50\times0.01\times(-1)=-0.5\ \mathrm{N}\cdot\ \mathrm{m}^2/\mathrm{C}$

(2) Right Face Flux (Φ_R):

(i) Electric field $E_R=500(0.2)=100\ \mathrm{N/C}$

(ii) The area vector points right (outward), so the angle is 0°.

(iii) $\Phi_R=E_R\cdot A\cdot\cos(0^\circ)=100\times0.01\times(1)=1.0\ \mathrm{N}\cdot\ \mathrm{m}^2/\mathrm{C}$

Net Flux (Φ_{net}):

$\Phi_{net} = \Phi_L + \Phi_R = -0.5 + 1.0 = 0.5\ \text{N} \cdot \text{m}^2/\text{C}$

(B) Calculate the Charge Within the Cube

Using Gauss's Law, the net flux is proportional to the enclosed charge (q):

$$\Phi_{net} = \frac{q}{\epsilon_0}$$

Where ϵ_0 (permittivity of free space) $\approx 8.854 \times 10^{-12} \text{C}^2/(\text{N} \cdot \text{m}^2)$.

- $q = \Phi_{net} \cdot \epsilon_0$
- $q = 0.5 \cdot (8.854 \times 10^{-12})$
- $q \approx 4.427 \times 10^{-12} \text{C}$ (or 4.427 pC)

Would you like to see how the calculation changes if the electric field was also present in the y or z directions?

155. **(A)** Current density

Definition:

Current density is the electric current flowing per unit cross-sectional area of a conductor:

$$\vec{j} = \frac{I}{A}$$

- It is a vector quantity, directed along the flow of positive charge.

Derivation of $\vec{j} = \alpha\vec{E}$

Let:

n = number of electrons per unit volume

e = charge of electron

m = mass of electron

τ = relaxation time

When electric field $\vec{E}$ is applied, force on electron:

$$\vec{F} = -e\vec{E}$$

Acceleration:

$$\vec{a} = \frac{\vec{F}}{m} = -\frac{e\vec{E}}{m}$$

Drift velocity:

$$\vec{v}_d = \vec{a}\tau = -\frac{e\vec{E}}{m}\tau$$

Current density:

$$\vec{j} = -ne\vec{v}_d$$

Substitute $\vec{v}_d$:

$$\vec{j} = -ne\left(\frac{e\vec{E}}{m}\tau\right) = \frac{ne^2\tau}{m}\vec{E}$$

$$\vec{j} = \alpha\vec{E}, \alpha = \frac{ne^2\tau}{m}$$

(B) Wheatstone Bridge

Definition:

A Wheatstone bridge is an arrangement of four resistors used to measure an unknown resistance accurately.

Condition for balance

In balanced condition, no current flows through the galvanometer.

Let the four resistances be P, Q, R, S

Condition:

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

$$PS = QR$$

Key point:

When the bridge is balanced, the potential difference across the galvanometer is zero, so it shows no deflection.

156. Given:

$E = 1.3384 \times 10^{-14}\ \text{J}, B = 2.0 \times 10^{-3}\ \text{T}, \frac{\rho}{\text{m}} = 1.0 \times 10^{8} \text{C/kg}$

(A) Speed of proton

$E=\frac{1}{2}mv^2 \Rightarrow v=\sqrt{\frac{2E}{m}}$

Using $\frac{q}{m} \Rightarrow m=\frac{q}{(q/m)}$

$v=\sqrt{2E\cdot\frac{q/m}{q}}=\sqrt{2E\cdot\frac{q}{m}\cdot\frac{1}{q}} \Rightarrow v=\sqrt{2E\cdot\frac{q}{m}\cdot\frac{1}{q}}$

Since $\frac{q}{m}=10^8$, take standard result:

$v=\sqrt{2E\cdot\frac{q}{m}\cdot\frac{1}{q}} \Rightarrow v=\sqrt{2E\cdot\frac{1}{m}}$

Simplifying numerically:

$v=\sqrt{2\times1.3384\times10^{-14}\times10^8}=\sqrt{2.6768\times10^{-6}}$

$v\approx1.64\times10^{-3}\times10^3=1.64\times10^3\ \mathrm{m/s}$

$v\approx1.6\times10^3\ \mathrm{m/s}$

(B) Acceleration

$a=v\cdot B\cdot\frac{q}{m}$

$a=(1.6\times10^3)(2\times10^{-3})(10^8)$

$a=3.2\times10^8\ \mathrm{m/s^2}$

$a=3.2\times10^8\ \mathrm{m/s^2}$

(C) Radius of path

$r=\frac{v}{B\cdot(q/m)}$

$r=\frac{1.6\times10^3}{(2\times10^{-3})(10^8)}=\frac{1.6\times10^3}{2\times10^5}$

$r=0.008\ \mathrm{m}$

$r=8\times10^{-3}\ \mathrm{m}$

157. Average Power Dissipated

The average power (P_{au}) in a series LCR circuit is the product of the RMS voltage, RMS current, and the power factor.

Expression:

$P_{av}=V_{rms}I_{rms}\cos\phi$

Where:

• $\cos\phi=\frac{R}{2}$ (Power Factor)

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

Resonant Frequency

Resonance occurs when the inductive reactance equals the capacitive reactance ($X_L=X_C$).making the circuit purely resistive.

Expression:

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

Where:

• L is Inductance

• C is Capacitance

• f_r is the Resonant Frequency in Hertz

158. **(A)** Justification with examples

The wavelength of electromagnetic waves is comparable to the size of the radiating system.

Examples:

(1) Radio waves:

Antennas used in radio transmission have lengths comparable to the wavelength (typically meters).

(2) Visible light:

Atoms/molecules (size $\sim 10^{-10}$ m) emit visible light of similar wavelength ($\sim 10^{-7}$ m).
(B) (i) Why short-wave bands are used for long-distance radio?
Short-wave radio waves undergo reflection (skywave propagation) from the ionosphere. This allows them to travel beyond the horizon and cover very large distances.
(ii) Why X-ray astronomy needs satellites?
• X-rays are absorbed by Earth's atmosphere, so they cannot reach the ground.
• Optical and radio waves can pass through the atmosphere, so telescopes for them can be groundbased.
Hence, X-ray telescopes must be placed in satellites.

159. Drawbacks of Rutherford model
(1) Atomic instability: Orbiting electrons should radiate energy and fall into nucleus.
(2) No line spectrum explanation: Cannot explain discrete spectra of atoms.
How Bohr removed them
• Electrons move in fixed stationary orbits without radiating energy.
• Radiation occurs only during transitions:
$$\Delta E = h\nu$$
• Angular momentum is quantized:
$$mvr = \frac{nh}{2\pi}$$
Bohr orbits not equally spaced
$$E_n = -\frac{13.6}{n^2}$$
Energy difference:
$$\Delta E = E_{n+1} - E_n \propto \left(\frac{1}{n^2} - \frac{1}{(n+1)^2}\right)$$
Since it depends on n, spacing is not equal and decreases as n increases.

160. **(A)** Properties of a Nucleus
(1) Nuclear Density: It is extremely high ($\approx 2.3 \times 10^{17}\ \mathrm{kg/m^3}$) and is constant regardless of the size of the nucleus.
(2) Short-range Force: Nucleons are bound by the Strong Nuclear Force, which is highly attractive but only acts over very short distances (femtometers).
(B) Comparison of Densities
An atom is mostly empty space. The nucleus contains 99.9% of the atom's mass but occupies only about 10^{-15} of its volume. Because such a large mass is concentrated into an incredibly tiny volume, the nuclear density is trillions of times greater than the overall atomic density.
(C) Proof: Density is Independent of Mass Number (A)
(1) Mass(M):Let m be the average mass of a nucleon. For a nucleus with mass number A :
$$M = mA$$
(2) Volume (V): Using the radius formula $R = R_0 A^{1/3}$:
$$V = \frac{4}{3}\pi R^3 = \frac{4}{3}\pi\left(R_0 A^{1/3}\right)^3 = \frac{4}{3}\pi R_0^3 A$$
(3) Density (ρ):
$$\rho = \frac{\text{Mass}}{\text{Volume}} = \frac{mA}{\frac{4}{3}\pi R_0^3 A}$$
$$\rho = \frac{3m}{4\pi R_0^3}$$
Conclusion: Since m and R_0 are constants, the density ρ is independent of A. Thus, all nuclei have approximately the same density.

161. **(i) (a)** Power of double convex lens
Using lens maker formula:
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
For a symmetrical double convex lens:
$$R_1 = R, R_2 = -R$$

$$\frac{1}{f} = (n-1)\left(\frac{1}{R} + \frac{1}{R}\right) = \frac{2(n-1)}{R}$$

So power:

$$P = \frac{1}{f} = \frac{2(n-1)}{R}$$

(ii) (d) When a double-convex lens is cut perpendicular to its principal axis, it is split into two identical plano-convex lenses.

(1) Original Lens: Has two curved surfaces, each contributing to the total power P.

(2) Cut Lens: Has only one curved surface (the other is flat with $R = \infty$), so it provides only half the refractive bending of the original lens.

Therefore, the power of one part is $P/2$.

(iii) (b) Power of the Combination

When two lenses are placed in contact, the total power is the sum of their individual powers ($P_{eq} = P_1 + P_2$)

• From the previous part, cutting the lens vertically resulted in two parts, each with power $P/2$.

• In the figure, these two parts are joined back together.

• Calculation: $\frac{P}{2} + \frac{P}{2} = P$.

(iv)(A) (b) Cutting Along the Principal Axis

In this scenario, the lens is cut horizontally (along the principal axis).

• Individual Power: Unlike the vertical cut, a horizontal cut does not change the radii of curvature (R_1 and R_2) or the refractive index of the material. Therefore, each half-lens still has the same power P as the original lens.

• Combination: When these two halves are placed together as shown in the second figure in this ques. they essentially function as the original lens would, maintaining the same focal properties.

OR

(B) (a) For lenses in contact, powers add:

$P = P_1 + P_2$

Given:

$f_1 = 60 \text{ cm} = 0.6 \text{ m}, f_2 = 20 \text{ cm} = 0.2 \text{ m}$

Power:

$$P_1 = \frac{1}{0.6} = 1.67D, P_2 = \frac{1}{0.2} = 5D$$

Total power:

$P = 1.67 + 5 = 6.67D \approx 6.6D$

162. **(i) (a)**

In a full-wave rectifier, rectification does not change RMS value (only waveform is flipped, not amplitude).

So:

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

(ii) (b) In full-wave rectifier, each diode conducts for only one half cycle, but alternately.

(iii) (c) In a full-wave rectifier (center-tap type), at any instant:

• One diode conducts (forward biased)

• The other is non-conducting (reverse biased)

(iv) (A)(b) Ripple frequency in half-wave rectifier

In a half-wave rectifier, only one half-cycle of AC is used, so the output frequency remains the same as the input frequency.

Given:

$f = 50$ Hz

Ripple frequency:

$f_r = f$

$f_r = 50$ Hz

OR

(B) (d) The diode is oriented from the input toward R_L(anode on input side, cathode on output side).

• When input is $+5$ V → diode is forward biased → current flows → output across $R_L \approx +5$ V

• When input is -5 V → diode is reverse biased → no current → output ≈ 0 V

So the output is a positive half-wave (only +5 V pulses, zero otherwise).

163. **(A)(i)** Potential Energy of an Electric Dipole

The potential energy U of an electric dipole $\vec{p}$ in a uniform electric field $\vec{E}$ is given by:
$U=-\vec{p}\cdot\vec{E}=-pE\cos\theta$
(a) Maximum Potential Energy: Occurs when $\cos\theta=-1$, i.e., $\theta=180^\circ$ (Antiparallel alignment). The dipole is in unstable equilibrium.
(b) Minimum Potential Energy: Occurs when $\cos\theta=1$, i.e., $\theta=0^\circ$ (Parallel alignment). The dipole is in stable equilibrium.
(1) Calculate work done
When a dipole is rotated from an angle θ_1 to θ_2 against the torque $\vec{\tau}=\vec{p}\times\vec{E}$, the work done is:
$$W=\int_{\theta_1}^{\theta_2}\tau d\theta=\int_{\theta_1}^{\theta_2} pE\sin\theta d\theta=pE[-\cos\theta]_{\theta_1}^{\theta_2}$$
(2) Define potential energy
Taking the reference point at $\theta_1=90^\circ$ (where $U=0$), the potential energy at angle θ is:
$U=pE[-\cos\theta-(-\cos 90^\circ)]=-pE\cos\theta=-\vec{p}\cdot\vec{E}$
(ii) Calculation of Torque
The torque is calculated as $\vec{\tau}=\vec{p}\times\vec{E}$. e
• Dipole moment $\vec{p}$: $q\cdot\vec{d}=1.0\times10^{-12}\mathrm{C}\times(3\hat{\imath}+4\hat{\jmath})\times10^{-3}$ m $=(3\hat{\imath}+4\hat{\jmath})\times10^{-15}\mathrm{C}\cdot$m.
• Electric field $\vec{\boldsymbol{E}}$: $1000\hat{\imath}$ V/m.
• Torque: $\vec{\tau}=[(3\hat{\imath}+4\hat{\jmath})\times10^{-15}]\times[1000\hat{\imath}]=4\times10^{-12}(\hat{\jmath}\times\hat{\imath})=-4\times10^{-12}\hat{k}$ N -m.
(B)(i) Potential due to Dipole θ
For a point x on the axis ($x\gg a$):
$$V=\frac{1}{4\pi\varepsilon_0}\left(\frac{q}{x-a}-\frac{q}{x+a}\right)=\frac{q}{4\pi\varepsilon_0}\left(\frac{2a}{x^2-a^2}\right)$$
Since $x>a, x^2-a^2\approx x^2$. Given $\vec{p}=(q\cdot 2a)\hat{\imath}$
$$V=\frac{1}{4\pi\varepsilon_0}\frac{p}{x^2}=\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}\cdot\hat{\imath}}{x^2}$$
(ii) New Charge on Sphere $\boldsymbol{S}_1$
The new charge on sphere S_1 is $2.0\times10^{-12}\mathrm{C}$ (or 2.0 pC).
(1) Find initial total charge
The charge density $\sigma=\frac{2}{x}\times10^{-9}\mathrm{C/m^2}$.
• $Q_1=\sigma(4\pi R_1^2)=\left(\frac{2}{\pi}\times10^{-9}\right)(4\pi\times0.01^2)=8\times10^{-13}\mathrm{C}$.
• $Q_2=\sigma(4\pi R_2^2)=\left(\frac{2}{\pi}\times10^{-9}\right)(4\pi\times0.03^2)=72\times10^{-13}\mathrm{C}$.
• Total Charge $Q_{\text{total}}=80\times10^{-13}\mathrm{C}=8.0\mathrm{pC}$.
(2) Apply condition for connection
When connected, they reach the same potential $V_1=V_2$:
$$\frac{kQ_1'}{R_1}=\frac{kQ_2'}{R_2}\Rightarrow\frac{Q_1'}{1}=\frac{Q_2'}{3}\Rightarrow Q_2'=3Q_1'$$
(3) Solve for $Q_1{}'$
Using conservation of charge: $Q_1{}'+3Q_1{}'=8.0\mathrm{pC}\Rightarrow 4Q_1{}'=8.0\mathrm{pC}\Rightarrow Q_1{}'=2.0\mathrm{pC}$.

164. **(A) (i)** Impedance of RC series circuit
Given:
$v=v_m\sin\omega t$
In RC series circuit
• Current I is same in both R and C
• Voltage across resistor: $V_R=IR$ (in phase with I)
• Voltage across capacitor: $V_C=\frac{I}{\Delta C}$ (lags by 90°)
So resultant voltage:
$$V=\sqrt{V_R^2+V_C^2}$$
$$V=I\sqrt{R^2+\left(\frac{1}{\omega C}\right)^2}$$

Hence impedance:

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

(ii) An inductor acts like a conductor in DC (steady state).
Reason:
$X_L = \omega L$
For DC :
$\omega = 0 \Rightarrow X_L = 0$
So:
• No opposition to current
• Inductor behaves like a short circuit (conductor)

OR

(B) (i) Step-up transformer
Principle:
Based on mutual induction:
Changing magnetic flux in primary induces emf in secondary
Working:
• AC in primary → alternating magnetic flux in core
• Flux links secondary - induced higher voltage (if turns more)
Energy losses (any three):
(1) Copper loss: heating in windings
(2) Eddy current loss: currents induced in core
(3) Hysteresis loss: repeated magnetization of core
(ii) Conservation of energy?
No violation.
Because:
• Voltage increases in secondary
• But current decreases proportionally
$V_p I_p = V_s I_s$ (ideal case)
So power remains conserved.
(iii) Numerical
Given:
$N_p = 200, N_s = 3000, V_p = 90\text{ V}, I_s = 2\text{ A}$
(1) Secondary voltage:

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

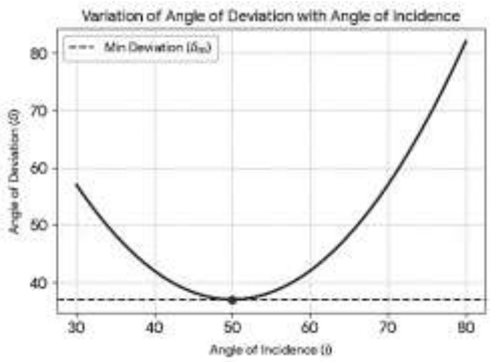
$$V_s = 90 \times \frac{3000}{200} = 90 \times 15 = 1350\text{ V}$$

$V_s = 1350\text{ V}$
(2) Primary current:
$V_p I_p = V_s I_s$

$$I_p = \frac{V_s I_s}{V_p} = \frac{1350 \times 2}{90} = 30\text{ A}$$

$I_p = 30\text{ A}$

165. **(A) (i)** Angle of Deviation vs. Angle of Incidence
The relationship between the angle of incidence (i) and the angle of deviation (δ) is nonlinear. As the angle of incidence increases, the deviation first decreases, reaches a minimum value, and then begins to increase again.



Definition of Angle of Minimum Deviation (δ_m) :
It is the smallest angle by which a ray of light is bent when passing through a prism. At this specific position, the ray passes symmetrically through the prism, such that the angle of incidence equals the angle of emergence ($i = e$).
(ii) Proof for Normal Incidence
For a ray incident normally on the first face:
(1) Angle of incidence $(i) = 0^\circ$.
(2) Angle of refraction $(r_1) = 0^\circ$ (since it passes undeviated into the prism).
(3) We know $r_1 + r_2 = A$. Since $r_1 = 0$, then $r_2 = A$.
(4) The total deviation is $\delta = (i - r_1) + (e - r_2)$. Substituting values: $\delta = (0 - 0) + (e - A) \Longrightarrow \mathbf{e} = \mathrm{A} + \delta$.
(5) Using Snell's law at the second face (from glass to air):

$$n = \frac{\sin(\text{ angle in air })}{\sin(\text{ angle in glaxs })} = \frac{\sin\epsilon}{\sin r_2}$$

Substituting e and r_2 :

$$n = \frac{\sin(A + \delta)}{\sin A} \text{ (Proved)}$$

(iii) Numerical Solution
Given: $n = \sqrt{2}, A = 60^\circ$ e
s Angle of Minimum Deviation (δ_m) :
Using the prism formula: $n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$

$$\sqrt{2} = \frac{\sin\left(\frac{60 + \delta_m}{2}\right)}{\sin(30^\circ)}$$

$$\sqrt{2} \times \frac{1}{2} = \sin\left(\frac{60 + \delta_m}{2}\right)$$

$$\frac{1}{\sqrt{2}} = \sin\left(\frac{60 + \delta_m}{2}\right)$$

Since $\sin 45^\circ = \frac{1}{\sqrt{2}}$:

$$45^\circ = \frac{60 + \delta_m}{2} \Longrightarrow 90 = 60 + \delta_m \Longrightarrow \delta_m = 30^\circ$$

(2) Angle of Incidence (i):
At minimum deviation, $i = \frac{A+\delta_\mathrm{m}}{2}$

$$i = \frac{60 + 30}{2} = \frac{90}{2}$$

$i = 45^\circ$

OR

(B) (i) Huygens' Principle and Law of Reflection
Huygens' Principle:
• Each point on a wavefront acts as a source of secondary spherical wavelets.
• The new wavefront is the forward tangential envelope of these wavelets.
Proof of $i = r$:
• In the reflection diagram, let v be the speed of light. $BC = AD = vt$ represents the distance traveled by the wavefront in time t.

• Triangles $\triangle ABC$ and $\triangle ADC$ are congruent (RHS) because AC is common, $BC = AD$, and both have a 90° angle.
• By congruence, $\angle BAC = \angle DCA \Longrightarrow$ i = r.
(ii) Coherent Sources
• Definition: Sources that emit light waves of the same frequency and maintain a constant phase difference.
• Independent Sodium Lamps: They cannot be coherent.
• Reason: Light emission is a random atomic process; independent lamps have rapidly and randomly changing phase differences, preventing a stable interference pattern.
(iii) Wavelength Calculation
For coincidence of bright fringes in YDSE:
• Formula: $n_1\lambda_1 = n_2\lambda_2$.
• Given: $n_1 = 5$ (known), $\lambda_1 = 520$ nm, $n_2 = 4$ (unknown).
• Calculation:
$5 \times 520 = 4 \times \lambda_2$
$\lambda_2 = \frac{2600}{4}$
• Result: $\lambda_2 = 650$ nm

166. **(d)** Charge on glass rod
$q = 4.8 \times 10^{-17}$C
Charge of one electron,
$e = 1.6 \times 10^{-19}$C
Number of electrons transferred:
$n = \frac{q}{e} = \frac{4.8 \times 10^{-17}}{1.6 \times 10^{-19}} = 300$
Glass rod becomes positively charged, so it loses electrons. No protons are transferred.

167. **(c)** Given:
$E = 3$ V, $r = 0.2\Omega$, $R = 5.8\Omega$
Current in circuit:
$I = \frac{E}{R + r} = \frac{3}{5.8 + 0.2} = \frac{3}{6} = 0.5$ A
Potential difference across cell:
$V = E - Ir = 3 - (0.5)(0.2) = 3 - 0.1 = 2.9$ V

168. **(d)** Magnetic field on the axis of a circular coil at a far off point behaves like magnetic dipole field:
$B \propto \frac{1}{r^3}$

169. **(b)** Magnetic field inside a solenoid:
$B = \mu_0 nI = \mu_0 \frac{N}{L} I$
$B = \frac{\mu_0 NI}{L}$

170. **(c)** Magnetic moment of first loop:
$M_1 = (3I)\pi a^2 = 3\pi I a^2$
Second loop:
$M_2 = I\pi(2a)^2 = 4\pi I a^2$
Since loops are perpendicular,
$M = \sqrt{M_1^2 + M_2^2} = \pi I a^2\sqrt{3^2 + 4^2} = 5\pi I a^2$

171. **(d)** Given:
$\phi = 6t^2 + 3t + 5$
Induced emf:
$e = \left|\frac{d\phi}{dt}\right| = |12t + 3|$
At $t = 1$ s :
$e = 12(1) + 3 = 15$ V
Current:

$$I = \frac{e}{R} = \frac{15}{3} = 5\ \text{A}$$

172. **(c)** Frequency order:

γ-rays $>$ ultraviolet $>$ microwaves

$v_2 > v_1 > v_3$

173. **(a)** In photoelectric effect, emission occurs only if incident radiation has minimum threshold frequency.

174. **(d)** In Bohr model:

$$L_n = \frac{nh}{2\pi}$$

For $n = 1$:

$$L_1 = \frac{h}{2\pi}$$

For $n = 3$:

$$L_3 = \frac{3h}{2\pi}$$

Increase:

$$\Delta L = L_3 - L_1 = \frac{3h}{2\pi} - \frac{h}{2\pi} = \frac{2h}{2\pi} = \frac{h}{\pi}$$

175. **(a)** Distance of closest approach:

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$$

$$\text{r} \propto \frac{Z}{mv^2}$$

176. **(a)** In forward biasing of a p-n junction:

• depletion layer width decreases
• potential barrier height decreases

177. **(d)** Donor impurity adds extra electrons and creates an energy level just below the conduction band.

So, formation of a new energy level just below the conduction band.

178. **(b)** Assertion (A) is true.

Different metals have different work functions because the electrons are bound with different energies in different metals.

Reason (R) is true.

Different metals do have different conductivities.

But conductivity is not the correct explanation for difference in work functions.

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

179. **(d)** Capacitive reactance is

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

So, when frequency (ω) increases, X_C decreases.

Hence, Assertion (A) is false.

Reason (R) is also false because the correct formula is

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

not ωC.

So, Both A and R are false.

180. **(a)** Adjacent turns of a current-carrying spring carry current in the same direction. Parallel currents in the same direction attract each other, so the turns move closer.

Thus, Assertion (A) is true.

Reason (R) is also true because there is indeed a magnetic force between adjacent current-carrying turns, and this force causes attraction.

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

181. **(a)** Assertion (A) is true.

Optical fibres transmit signals with very little loss of energy.

Reason (R) is also true.

Optical fibres work on the principle of total internal reflection.
Because repeated total internal reflection confines light within the fibre and prevents major energy loss, R correctly explains A.
So, Both A and R are true, and R is the correct explanation of A .

182. For cells in series:
Total emf $= 2E$
Total internal resistance $= 2r$
Given current $I = 1.5$ A and external resistance $R = 8\Omega$,
$$1.5 = \frac{2E}{8 + 2r}$$
$2E = 12 + 3r$ ...(i)
For cells in parallel:
Equivalent emf $= E$
Equivalent internal resistance $= \frac{r}{2}$
Given current $I = 1.0$ A,
$$1 = \frac{E}{8 + \frac{r}{2}}$$
$E = 8 + \frac{r}{2}$ ....(ii)
From (2).
$2E = 16 + r$
Comparing with (1):
$16 + r = 12 + r$
$4 = 2r$
$r = 2\Omega$
Now from (2).
$$E = 8 + \frac{2}{2} = 9V$$
Hence,
$r = 2\Omega, E = 9$ V

183. **(A)** The focal length of a lens depends on:
(1) Refractive index of the material of the lens
(2) Refractive index of the surrounding medium
(3) Radii of curvature of the two surfaces of the lens
Lens maker formula:
$$\frac{1}{f} = \left(\frac{n_L}{n_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$
where n_ℓ is refractive index of lens material and n_m is refractive index of surrounding medium.
A thin biconvex glass lens submerged in water still behaves as a converging lens, but its focal length increases (power decreases).
Reason: In water, the relative refractive index of glass decreases, so the bending of light rays becomes less.

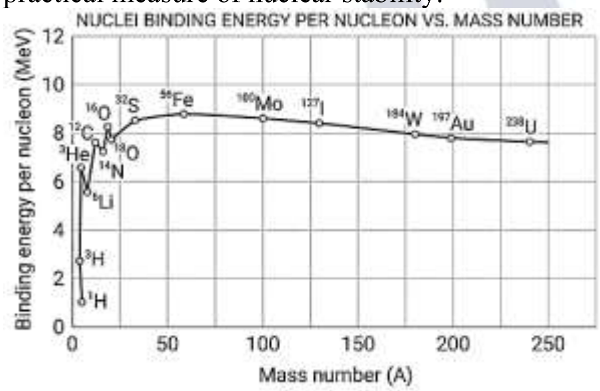
OR

(B) In Young's double slit experiment, fringe width is
$$\beta = \frac{\Delta D}{d}$$
where
$\lambda =$ wavelength
$D =$ distance of screen from slits,
$d =$ separation between slits.
(i) If slit separation is reduced to half:
$$d \rightarrow \frac{d}{2}$$
$$\beta' = \frac{\lambda D}{d/2} = 2\beta$$

Fringe width becomes double.
(ii) If screen distance is reduced to half.
$D \to \frac{D}{2}$
$\beta' = \frac{\lambda(D/2)}{d} = \frac{\beta}{2}$
Fringe width becomes half.

184. For two lenses in contact:
$P = P_1 + P_2$
Given:
$P = 10D$
Let focal length of $L_2 = f$.
Then focal length of $L_1 = 4f$.
Power:
$P_1 = \frac{1}{4f}, P_2 = \frac{1}{f}$
So,
$\frac{1}{4f} + \frac{1}{f} = 10$
$\frac{5}{4f} = 10$
$f = \frac{5}{40} = \frac{1}{8}m$
Hence,
$f_2 = \frac{1}{8}m = 12.5cm$
and
$f_1 = 4f_2 = 50$ cm
Therefore,
$f_1 = 50$ cm, $f_2 = 12.5$ cm

185. Mass Defect vs. Binding Energy per Nucleon
• Mass Defect (Δm) : The difference between the total mass of individual protons and neutrons and the actual mass of the nucleus. It represents the mass converted into energy during nuclear formation.
• Binding Energy per Nucleon (BE/A) : The total binding energy divided by the number of nucleons. It is the practical measure of nuclear stability.



Why BE/A is Constant (30 < A < 170)
The value stays nearly constant at about 8.5 MeV /nucleon due to:
(1) Short-Range Force: The strong nuclear force only acts over very small distances approx 10^{-15} m
(2) Saturation Effect: A nucleon only interacts with its immediate neighbors. In this mass range, a nucleon is "saturated" by its neighbors; adding more nucleons to the nucleus doesn't increase the binding energy of that specific nucleon because they are too far away to exert a force.
Consequently, the total binding energy is proportional to A, making the ratio (BE/A) a constant.

186. For choosing dopants for silicon or germanium, the following considerations are important:
(1) Atomic size should be nearly equal to that of Si or Ge

So that the impurity atom can easily fit into the crystal lattice without disturbing its structure.
(2) Valence electrons should differ appropriately
- For n -type semiconductor, pentavalent impurities (P, As, Sb) are used because they provide extra electrons.
- For p-type semiconductor, trivalent impurities (B, Al, Ga, In) are used because they create holes.

(3) Impurity atoms should not change the crystal structure significantly
This ensures proper semiconductor behaviour and stable conduction.
Justification:
If the dopant has suitable size and valency, it forms covalent bonds with neighbouring atoms properly and introduces free charge carriers (electrons or holes), thereby increasing conductivity without damaging the crystal lattice.

187. **(A)** (1) Definitions:
- Temperature Coefficient of Resistance (α): The fractional change in resistance per unit degree rise in temperature.
- Electrical Conductivity (σ): The reciprocal of resistivity ($\sigma = 1/\rho$); it measures a material's ability to conduct current.

(2) Why Constantan/Manganin?
- Low α : Their resistance barely changes with temperature, ensuring stability.
- High Resistivity: Allows for compact standard resistors.

OR

(B) (1) Drift Velocity (v_{id}) :
The average velocity gained by free electrons in a conductor when an external electric field is applied.
(2) Proof $(\rho \propto 1/\tau)$:
- Current $I = neAv_d$
- Drift velocity $v_d = \frac{cE_r}{m}$
- Substitute $v_d : I = neA\left(\frac{eEr}{m}\right)$
- Substitute $E = \frac{V}{l} : I = \frac{n\epsilon^2 A\tau V}{ml}$
- Since $R = \frac{V}{I} = \frac{m}{nc^2\tau} \cdot \frac{l}{A}$
- Comparing with $R = \rho\frac{l}{\Lambda}$, we get:

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

Conclusion: Thus, resistivity is inversely proportional to relaxation time ($\rho \propto 1/\tau$).

188. Force between two parallel current-carrying wires is

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

Given:
$I_1 = 6\ A, I_2 = 8\ A$
$d = 10\ cm = 0.1\ m$
$l = 10\ cm = 0.1\ m$
$\mu_0 = 4\pi \times 10^{-7} Hm^{-1}$
Substituting,

$$F = \frac{4\pi \times 10^{-7} \times 6 \times 8 \times 0.1}{2\pi \times 0.1}$$

$F = 9.6 \times 10^{-6} N$
$F = 9.6 \times 10^{-6} N$
Since the currents are in opposite directions, the force between the wires is repulsive.

189. Brightness of the bulb depends on the current in the circuit.
For an inductor,
$X_L = \omega L$
Greater reactance means smaller current and dimmer bulb.
(A) Iron rod inserted in the inductor
Insertion of iron increases inductance L.
Hence X_L increases, current decreases.

So, the bulb glows dimmer.
(B) Number of turns in the inductor is decreased
Inductance decreases when number of turns decreases.
Thus X_L decreases and current increases.
So, the bulb glows brighter.
(C) Capacitor with $X_C = X_L$ connected in series
Net reactance:
$X = X_L - X_C = 0$
Circuit becomes resonant and impedance becomes minimum.
Current becomes maximum.
So, the bulb glows maximum brightness.

190. Displacement current

The current associated with the time rate of change of electric flux in a region where no actual charge flow occurs is called displacement current.

It is given by

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

where Φ_E is electric flux.
Proof that displacement current equals conduction current during charging of a capacitor Consider a capacitor being charged by a current I.
Charge on capacitor at any instant
$Q = CV$
Electric field between plates:

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

Electric flux through the plates:

$$\Phi_E = EA$$

$$\Phi_E = \frac{Q}{\varepsilon_0 A} \times A = \frac{Q}{\varepsilon_0}$$

Displacement current:

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

Substituting $\Phi_E = \frac{Q}{s_0}$.

$$I_d = \varepsilon_0 \frac{d}{dt}\left(\frac{Q}{\varepsilon_0}\right)$$

$$I_d = \frac{dQ}{dt}$$

But, $\frac{dQ}{dt} = I$
Therefore,
$I_d = I$
Hence, during charging of a capacitor, displacement current is equal to conduction current in the circuit.

191. Reason: The speed of emitted photoelectrons depends on the work function of the metal because an electron's maximum kinetic energy (K_{max}) is determined by the difference between the incident photon energy (hv) and the work function (ϕ). Thus, surfaces with lower work functions leave more residual energy, resulting in higher electron speeds.

(A) The speed of emitted electrons depends on the work function of the photosensitive surface, for the incident radiation of a given frequency.

• Reason: According to Einstein's photoelectric equation, $K_{max} = h_v - \phi$, where $K_{max} = \frac{1}{2}mv^2$. For a given frequency v of incident radiation, the photon energy (h_v) is constant. Therefore, a metal with a lower work function (ϕ) will impart greater maximum kinetic energy and higher velocity to the emitted photoelectrons.
(B) The stopping potential (V_O) increases linearly with the frequency of incident radiation, for a given photosensitive surface.

• Reason: The maximum kinetic energy of emitted electrons is related to the stopping potential by $K_{max} = eV_0$. Substituting this into Einstein's equation gives $eV_0 = h_v - \phi$, or $V_0 = \left(\frac{h}{e}\right) v - \frac{\phi}{e}$. Since h, e, and ϕ are constants for a given surface, the stopping potential varies linearly with the incident frequency v.

(C) The photoelectric current increases linearly with the intensity of incident radiation, for a given surface.

• Reason: The intensity of incident radiation is directly proportional to the number of photons falling on the metal surface per unit time. In the photoelectric effect, one photon ejects exactly one electron (assuming the frequency is above the threshold). Therefore, increasing the intensity increases the number of emitted photoelectrons, which linearly increases the photoelectric current.

192. The emission spectrum of a hydrogen atom is explained by Bohr's Postulates, which state that an electron emits a photon when it jumps from a higher energy outer orbit (n_2) to a lower energy inner orbit (n_1).

Origin of the Series

(1) Lyman Series:

• Origin: This series is formed when electrons transition from any outer orbit ($n_2 = 2,3,4, \ldots$) to the first orbit ($n_1 = 1$).

• Spectral Region: It lies in the Ultraviolet (UV) region.

(2) Balmer Series:

• Origin: This series is formed when electrons transition from outer orbits ($n_2 = 3,4,5, \ldots$) to the second orbit ($n_1 = 2$).

• Spectral Region: It lies in the Visible region.

Determining Wavelength (λ)

The wavelength of the emitted radiation is calculated using the Rydberg Formula:

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

(Where R is the Rydberg constant $\approx 1.097 \times 10^7 \mathrm{~m}^{-1}$)

(1) Maximum Wavelength (λ_{max})

• Condition: This corresponds to the minimum energy transition.

• Calculation: It occurs when the electron jumps from the nearest higher orbit ($n_2 = n_1 + 1$).

• Example (Lyman): Transition from $n = 2$ to $n = 1$.

(2) Minimum Wavelength (λ_{min})

• Condition: This corresponds to the maximum energy transition (also called the Series Limit).

• Calculation: It occurs when the electron jumps from an orbit at infinity ($n_2 = \infty$) to the series' base orbit (n_1).

• Example (Lyman): Transition from $n = \infty$ to $n = 1$. In this case, $1/n_2^2$ becomes zero.

193. When atoms are isolated, their electrons occupy definite discrete energy levels. In a solid, a very large number of atoms come very close to each other. Due to interaction between neighbouring atoms, the discrete energy levels split into a large number of very closely spaced levels.

These closely spaced energy levels form energy bands.

Formation of Energy Bands

As atoms approach each other to form a solid:

• outer electron wave functions overlap,

• interaction between atoms causes splitting of energy levels,

• the split levels become so closely spaced that they appear continuous.

Thus, groups of closely spaced levels are called energy bands.

Valence Band

The highest energy band that is normally filled with electrons at 0 K is called the valence band.

Electrons in this band are bound to atoms and generally do not contribute to conduction.

Conduction Band

The energy band above the valence band in which electrons are free to move and conduct electricity is called the conduction band.

Electrons present in this band participate in electrical conduction.

The gap between valence band and conduction band is called the forbidden energy gap (band gap).

194. **(i) (a)** When light enters glass from air:

• speed decreases because glass is optically denser,

• frequency remains constant,

• therefore wavelength also decreases since

$v = \nu\lambda$

Hence, both v and λ decrease.

(ii) (A) (b) Angle of incidence:

$i = 45°$

Deviation:

$\delta = i - r$

Given:

$\delta = 15°$

So,

$r = 45° - 15° = 30°$

Using Snell's law:

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

$$\mu = \frac{\sin 45°}{\sin 30°} = \frac{1/\sqrt{2}}{1/2} = \sqrt{2}$$

OR

(ii) (B) For emergence at the surface,

$$\tan C = \frac{r}{H}$$

Given:

$$r = \frac{H}{\sqrt{3}}$$

$$\tan C = \frac{1}{\sqrt{3}}$$

$C = 30°$

Refractive index:

$$\mu = \frac{1}{\sin C} = \frac{1}{\sin 30°} = 2$$

(iii) (c) In an optical fibre, total internal reflection occurs at the core-cladding boundary. Therefore, refractive index of the core must be slightly greater than that of the cladding.

$\mu_1 > \mu_2$

So, μ_1 is slightly greater than μ_2

(iv) (d) Frequency of light does not change when it passes from one medium to another.

In air:

$$\nu = \frac{c}{\lambda}$$

Hence, in the medium also,

$$\nu = \frac{c}{\lambda}$$

195. **(i) (c)** In a uniform electric field, forces on the two charges of the dipole are equal and opposite, so net force is zero.

But since the dipole is not aligned with the field, a torque acts on it.

A torque but no net force

(ii) (b) For a point on the axis of a dipole at large distance,

$$F \propto \frac{1}{x^3}$$

If distance is doubled:

$$F' = \frac{F}{2^3} = \frac{F}{8}$$

(iii) (c) The two dipole moments are perpendicular and equal in magnitude p.

Resultant dipole moment:

$$P = \sqrt{p^2 + p^2} = \sqrt{2p^2} = p\sqrt{2}$$

(iv) (A) (b) Maximum torque on a dipole is

$\tau_{\max} = pE$

Given:

$p = 3.0 \times 10^{-30} \mathrm{C} - m$
$E = 2 \times 10^{4} NC^{-1}$
$\tau_{\max} = 3.0 \times 10^{-30} \times 2 \times 10^{4}$
$\tau_{\max} = 6.0 \times 10^{-26}\ \mathrm{N} - m$

OR

(iv) (B) (c)
Dipole moment:
$p = qd$
$q = 2pC = 2 \times 10^{-12} C$
$d = 1\ \mathrm{mm} = 10^{-3}\ \mathrm{m}$
$p = 2 \times 10^{-12} \times 10^{-3} = 2 \times 10^{-15} C - m$
Work done in rotating dipole from stable to unstable equilibrium:
$W = 2pE$
$W = 2 \times 2 \times 10^{-15} \times 2 \times 10^{5}$
$W = 8 \times 10^{-10}\ \mathrm{J}$

196. **(A) (i)** Capacitor Changes (Battery Disconnected)
When the battery is disconnected, the charge (Q) on the capacitor remains constant because there is no path for the charge to leave or enter the plates.
(1) Capacitance (C)
• Effect: The capacitance doubles.
• Justification: Capacitance is given by $\mathrm{C} = \frac{\mathrm{cd}}{\mathrm{d}}$. Since the separation (d) is halved$(\mathrm{d}' = \frac{\mathrm{d}}{2})$, the new capacitance $\mathrm{C}' = \frac{\mathrm{c_a A}}{\mathrm{d}/2} = 2\mathrm{C}$.
(2) Electric Field (E)
• Effect: The electric field remains unchanged.
• Justification: The electric field between the plates is $\mathrm{E} = \frac{\sigma}{\mathrm{c_0}} = \frac{\mathrm{Q}}{\Lambda_0}$. Since both the charge (Q)and the area (A) are constant, the electric field does not depend on the separation (d).
(3) Energy Stored (U)
• Effect: The energy stored is halved.
• Justification: Energy is given by $\mathrm{U} = \frac{\mathrm{Q}^2}{2\mathrm{C}}$. Since Q is constant and the new capacitance $\mathrm{C}' = 2\mathrm{C}$:

$$\mathrm{U}' = \frac{\mathrm{Q}^2}{2(2\mathrm{C})} = \frac{1}{2}\left(\frac{\mathrm{Q}^2}{2\mathrm{C}}\right) = \frac{\mathrm{U}}{2}$$

(ii)$\mathrm{Q} = \mathrm{CV} = 20 \times 10^{-6} \times 30 = 600\mu\mathrm{C}$
$\mathrm{C_{eq}} = 20 + 30 = 50\mu\mathrm{F}$
Common potential:

$$\mathrm{V} = \frac{600}{50} = 12\ \mathrm{V}$$

Charges:
$\mathrm{Q_1} = 20 \times 12 = 240\mu\mathrm{C}$
$\mathrm{Q_2} = 30 \times 12 = 360\mu\mathrm{C}$
$\mathrm{Q_1} = 240\mu\mathrm{C}, \mathrm{Q_2} = 360\mu\mathrm{C}$

OR

(B) (i) Expression for Electric Potential
To find the potential V at distance r from charge Q, we calculate the work done per unit test charge ($\mathrm{q_0}$) in bringing it from infinity (∞) to r :
(1) Work Done (dW): $\mathrm{dW} = -\mathrm{F} \cdot \mathrm{dx} = -\left(\frac{1}{4\pi\varepsilon_0} \frac{\mathrm{Q_{01}}}{\mathrm{x}^2}\right) \mathrm{dx}$.
(2) Integration: $\mathrm{W} = \int_{\infty}^{\mathrm{r}} -\frac{1}{4\pi\mathrm{c_0}} \frac{\mathrm{Q_0}}{\mathrm{x}^2} \mathrm{dx} = \frac{1}{4\pi\mathrm{c_0}} \frac{\mathrm{Q_0}}{\mathrm{r}}$.
(3) Potential ($\mathrm{V} = \mathrm{W}/\mathrm{q_0}$):

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

(ii) Electrostatic Energy Calculation
Total Energy (U) = (Potential energy of $\mathrm{q_1}$ in E) +(Potential energy of $\mathrm{q_2}$ in E) + (Mutual interaction energy).

Given:
• $q_1 = 4 \times 10^{-6}$C, $q_2 = -2 \times 10^{-6}$C.
• $E = A/r^2 \Longrightarrow V = A/r$ (where $A = 9 \times 10^5$).
• $r_{12} = 10$ cm $= 0.1$ m.
(1) Energy in External Field:
(Note: If q_1 is at the origin (0,0,0), V_1 is technically undefined for $V = A/r$. In standard physics problems, if q_1 is at a non-zero distance like r_1, we calculate $q_1(A/r_1)$. For q_2 at $r_2 = 0.1$ m):

$$U_{ext2} = q_2\left(\frac{A}{r_2}\right) = (-2 \times 10^{-6})\left(\frac{9 \times 10^5}{0.1}\right) = -18 \text{ J}$$

(2) Mutual Interaction Energy:

$$U_{mut} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_{12}} = \frac{(9 \times 10^9)(4 \times 10^{-6})(-2 \times 10^{-6})}{0.1} = -0.72 \text{ J}$$

Total Energy:
$U = U_{ext\,1} + (-18 \text{ J}) + (-0.72 \text{ J})$
(If q_1 is placed at a distance where $U_{ext\,1}$ is negligible or zero, $U \approx -18.72$ J).

197. **(A) (i)** Self-inductance:
The property of a coil by virtue of which it opposes the change in current through it by inducing emf in itself is called self-inductance.

$$L = \frac{N\phi}{I}$$

For a solenoid:
Magnetic field.
$B = \mu_0 nI$
Flux through each turn,
$\phi = BA = \mu_0 nIA$
Total flux linked:
$N\phi = (nL)(\mu_0 nIA)$
$N\phi = \mu_0 n^2 ALI$
Hence,
$L = \mu_0 n^2 AL$
(ii) Given:
$L = 50mH = 0.05H$
$\Delta I = 10A$
Using:

$$L = \frac{\Delta(N\phi)}{\Delta I}$$

$\Delta(N\phi) = L\Delta I$
$= 0.05 \times 10 = 0.5$ Wb
0.5 Wb

OR

(B) (i) In an ac generator, a coil rotates in a magnetic field. Due to continuous change in magnetic flux linked with the coil, an alternating emf is induced.
Flux linked:
$\phi = NBA\cos\omega t$
Induced emf:

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

$e = NBA\omega\sin\omega t$
Let
$E_0 = NBA\omega$
Then,
$e = E_0\sin\omega t$
(ii) At resonance:

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

Given:
$L = 2H, C = 32\mu F = 32 \times 10^{-6} F$
$\omega_0 = \dfrac{1}{\sqrt{2 \times 32 \times 10^{-6}}}$
$= \dfrac{1}{8 \times 10^{-3}}$
$= 125 \text{rad s}^{-1}$
125rad s^{-1}

198. **(A) (i)** Coherent Sources & Young's Double-Slit Experiment

• Coherent Sources: These are sources of light that emit waves of the same frequency (or wavelength) and have a constant phase difference over time.
• Obtaining Coherent Sources: In Young's experiment, a single primary light source illuminates two closely spaced narrow slits (S_1 and S_2). Because both slits are derived from the same wavefront of the single source, any phase changes in the source occur simultaneously at both slits, ensuring they remain coherent.
• Conditions for Interference:
• Constructive Interference (Bright Fringes): Occurs when the path difference (Δp) is an integral multiple of the wavelength: $\Delta p = n\lambda$ (where $n = 0,1,2, \ldots$).
• Destructive Interference (Dark Fringes): Occurs when the path difference is an odd multiple of half-wavelengths: $\Delta p = (2n-1)\frac{\lambda}{2}$ (where $n = 1,2,3, \ldots$).

(ii) Numerical (Convex Mirror)
• Given: Object distance $u = -20$ cm, Radius of curvature $R = +60$ cm.
• Focal Length: $f = \frac{R}{2} = \frac{60}{2} = +30$ cm.
• Mirror Formula: $\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \Longrightarrow \frac{1}{v} + \frac{1}{-20} = \frac{1}{30}$
• $\frac{1}{v} = \frac{1}{30} + \frac{1}{20} = \frac{2+3}{60} = \frac{5}{60} = \frac{1}{12}$
• Result: $v = +12$ cm.
• The image is formed 12 cm behind the mirror. Since $\boldsymbol{v}$ is positive, the image is virtual (and erect).

OR

(B) (i) Microscope Reasons
(1) Multicomponent Lenses: Used to correct optical aberrations (like chromatic and spherical aberration) to produce a sharper, clearer image.
(2) Small Focal Lengths: The magnification of a microscope is roughly $M \approx \frac{L \cdot D}{f_o \cdot f_e}$. By keeping both focal lengths small, the magnifying power is significantly increased.
(3) Eye Position (Eye-ring): The "eye-ring" (image of the objective formed by the eyepiece) is located slightly behind the eyepiece. Placing the eye here allows it to intercept all the light rays exiting the system, providing the maximum field of view. ©

(ii) Partition Wall (Diffraction)
• Bending of waves (diffraction) is significant only when the obstacle size is comparable to the wavelength.
• Sound waves have large wavelengths (approx. 1 m), which easily bend around a 6 m wall.
• Light waves have extremely tiny wavelengths (approx. 10^{-7} m). For such small wavelengths, the diffraction around a 6 m wall is negligible, so light travels in straight lines and the students cannot see each other.