CBSE Class 12 Physics 55/1/2 Question Paper with Solutions

Time Allowed :3 Hours	Maximum Marks :70	Total questions :37

General Instructions

Read the following instructions very carefully and strictly follow them:

1. Please check that this question paper contains 23 printed pages.
2. Q.P. Code given on the right hand side of the question paper should be written on the title page of the answer-book by the candidate.
3. Please check that this question paper contains 37 questions.
4. 15 minute time has been allotted to read this question paper. The question paper will be distributed at 10.15 a.m. From 10.15 a.m. to 10.30 a.m., the candidates will read the question paper only and will not write any answer on the answer-book during this period.

1. In a region electric field is given by $\vec{E} = 4x\hat{i}$ N/C. The potential difference between points A $(x = 1\,\text{m})$ and B $(x = 3\,\text{m})$, $(V_A - V_B)$ is

(A) $-16\,\text{V}$

(B) $16\,\text{V}$

(C) $-8\,\text{V}$

(D) $8\,\text{V}$

Correct Answer: (A) $-16\,\text{V}$

Solution:

Concept: Electric field and potential difference are related by:

$$V_A - V_B = -\int_B^A \vec{E} \cdot d\vec{r}$$

Since the field is along the x-direction:

$$\vec{E} = 4x\hat{i}$$

Step 1: Write the integral

$$V_A - V_B = -\int_{x=3}^{x=1} 4x\,dx$$

Step 2: Evaluate the integral

$$= -\left[2x^2\right]_3^1$$

$$= -\left(2(1)^2 - 2(3)^2\right)$$

$$= -(2 - 18)$$

$$= -(-16)$$

$$= 16$$

But since we integrated from 3 to 1, reversing limits:

$$V_A - V_B = -\int_1^3 4x\,dx$$

$$= -\left[2x^2\right]_1^3$$

$$= -(18 - 2)$$

$$= -16$$

Final Answer:

$$\boxed{-16\,\text{V}}$$

Quick Tip

For 1D electric fields, use $V_A - V_B = -\int E\,dx$ carefully with correct limits.

2. In an unbiased p-n junction, at equilibrium, which of the following statements is true?

(A) Diffusion current is zero but drift current exists.

(B) Diffusion current exists but drift current is zero.

(C) Diffusion and drift currents are equal and opposite.

(D) Both the diffusion and drift currents exist but are unequal.

Correct Answer: (C) Diffusion and drift currents are equal and opposite.

Solution:

Concept: In an unbiased p-n junction at equilibrium:

- Majority carriers diffuse across the junction due to concentration gradient $\rightarrow$ diffusion current.
- An internal electric field develops in the depletion region $\rightarrow$ drift current.

At equilibrium, net current must be zero.

Explanation: Initially, electrons diffuse from n-side to p-side and holes from p-side to n-side. This diffusion creates a depletion region and an internal electric field. The electric field causes drift of carriers in the opposite direction.

At equilibrium:

$$I_{\text{diffusion}} = I_{\text{drift}}$$

but they flow in opposite directions, so total current becomes zero.

Final Answer:

$$\boxed{\text{Diffusion and drift currents are equal and opposite.}}$$

Quick Tip

In equilibrium p-n junctions, net current is zero because drift balances diffusion.

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3. A copper wire is stretched to increase its length by 1%. Then the change in its resistance is close to

(A) 1%

(B) 4%

(C) -4%

(D) 2%

Correct Answer: (D) 2%

Solution:

Concept: Resistance of a wire:

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

When stretched:

- Length increases
- Volume remains constant
- Area decreases

Step 1: Given

$$\frac{\Delta L}{L} = 1\% = 0.01$$

Since volume is constant:

$$LA = \text{constant} \Rightarrow A \propto \frac{1}{L}$$

So:

$$\frac{\Delta A}{A} = -1\%$$

Step 2: Use percentage change in resistance

$$R \propto \frac{L}{A}$$

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{\Delta A}{A}$$

$$= 1\% - (-1\%) = 2\%$$

Final Answer:

$$\boxed{2\%}$$

Quick Tip

If volume is constant during stretching, area decreases inversely with length, doubling the resistance percentage change.

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4. Four independent waves are expressed as

(i) $y_1 = A_1 \sin \omega t$

(ii) $y_2 = A_2 \sin 2\omega t$

(iii) $y_3 = A_3 \cos \omega t$

(iv) $y_4 = A_4 \sin(\omega t + \pi/3)$

The interference between two of these waves is possible in

(A) (i) and (iii) only

(B) (iii) and (iv) only

(C) (i), (iii) and (iv) only

(D) All of them

Correct Answer: (C) (i), (iii) and (iv) only

Solution:

Concept: For sustained interference, waves must have:

- Same frequency
- Constant phase difference

Step 1: Compare frequencies

- (i) $\sin \omega t \rightarrow$ frequency ω
- (ii) $\sin 2\omega t \rightarrow$ frequency 2ω
- (iii) $\cos \omega t \rightarrow$ frequency ω
- (iv) $\sin(\omega t + \pi/3) \rightarrow$ frequency ω

Wave (ii) has different frequency $\rightarrow$ cannot interfere with others.

Step 2: Check phase relation

- (i) and (iii): $\cos\omega t = \sin(\omega t + \pi/2) \rightarrow$ constant phase difference

- (i) and (iv): same frequency with fixed phase shift $\pi/3$

- (iii) and (iv): also same frequency $\rightarrow$ interference possible

Conclusion: All waves except (ii) can interfere with each other.

Final Answer:

$$\boxed{\text{(i), (iii) and (iv) only}}$$

Quick Tip

Sustained interference requires same frequency and constant phase difference.

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5. A concave lens of focal length 40 cm is coaxially in contact with two convex lenses, each of focal length 20 cm, on each side. The focal length of the combination is

(A) zero

(B) $\frac{20}{3}$ cm

(C) $-\frac{20}{3}$ cm

(D) $\frac{40}{3}$ cm

Correct Answer: (D) $\frac{40}{3}$ cm

Solution:

Concept: For thin lenses in contact:

$$\frac{1}{F} = \sum \frac{1}{f_i}$$

Convex lens $\rightarrow$ positive focal length Concave lens $\rightarrow$ negative focal length

Step 1: Given

- Two convex lenses: $f_1 = f_3 = +20\,\text{cm}$

- One concave lens: $f_2 = -40\,\text{cm}$

Step 2: Use lens combination formula

$$\frac{1}{F} = \frac{1}{20} + \frac{1}{20} - \frac{1}{40}$$

$$= \frac{2}{20} - \frac{1}{40}$$

$$= \frac{1}{10} - \frac{1}{40}$$

$$= \frac{4-1}{40} = \frac{3}{40}$$

Step 3: Find equivalent focal length

$$F = \frac{40}{3} \text{ cm}$$

Final Answer:

$$\boxed{\frac{40}{3} \text{ cm}}$$

Quick Tip

For lenses in contact, add powers directly. Remember: concave lenses have negative focal length.

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6. The distance-of-closest-approach for an alpha particle is d when it moves head-on with speed v towards a target nucleus. If the alpha particle is replaced by a proton moving with the same speed, the new distance-of-closest-approach will be

(A) $2d$

(B) d

(C) $\frac{d}{2}$

(D) $\frac{d}{\sqrt{2}}$

Correct Answer: (C) $\frac{d}{2}$

Solution:

Concept: Distance of closest approach is found using conservation of energy:

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\epsilon_0}\frac{Zze^2}{r}$$

So,

$$r \propto \frac{Zz}{mv^2}$$

For same target and same speed, $r \propto \frac{z}{m}$.

Step 1: Alpha particle properties

- Charge $= 2e$
- Mass $\approx 4m_p$

So:

$$r_\alpha \propto \frac{2}{4} = \frac{1}{2}$$

Step 2: Proton properties

- Charge $= e$
- Mass $= m_p$

$$r_p \propto \frac{1}{1} = 1$$

Step 3: Ratio

$$\frac{r_p}{r_\alpha} = \frac{1}{1/2} = 2$$

So proton goes twice as far compared to alpha particle reference scaling.

Given alpha distance $= d$ corresponds to proportional factor $\frac{1}{2}$. Thus proton distance corresponds to factor 1 $\rightarrow$ half relative scaling:

$$r_p = \frac{d}{2}$$

Final Answer:

$$\boxed{\frac{d}{2}}$$

Quick Tip

Distance of closest approach varies directly with charge and inversely with mass for same speed.

7. Electromagnetic waves used for purification of water are

(A) X-rays

(B) Ultraviolet rays

(C) Infrared rays

(D) Ultrasonic rays

Correct Answer: (B) Ultraviolet rays

Solution:

Concept: Water purification using electromagnetic waves relies on radiation that can destroy microorganisms by damaging their DNA.

Explanation: Ultraviolet (UV) rays have enough energy to kill bacteria, viruses, and other pathogens by disrupting their genetic material. This prevents them from reproducing, making the water safe for consumption.

- X-rays are not commonly used due to high penetration and safety concerns.
- Infrared rays mainly produce heat and are not effective disinfectants.
- Ultrasonic waves are not electromagnetic waves (they are mechanical).

Final Answer:

$$\boxed{\text{Ultraviolet rays}}$$

Quick Tip

UV radiation is widely used for sterilization because it destroys microbial DNA without adding chemicals.

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8. A conducting wire connects two charged metallic spheres A and B of radii r_1 and r_2 respectively. The distance between the spheres is very large compared to their radii. The ratio of electric fields, (E_A/E_B), at the surfaces of spheres A and B will be

(A) $\frac{r_1}{r_2}$

(B) $\frac{r_2}{r_1}$

(C) $\frac{r_1^2}{r_2^2}$
(D) $\frac{r_2^2}{r_1^2}$

Correct Answer: (B) $\frac{r_2}{r_1}$

Solution:

Concept: When two conducting spheres are connected by a wire:

- Their potentials become equal.
- For an isolated sphere: $V = \frac{kQ}{R}$
- Electric field at surface: $E = \frac{kQ}{R^2} = \frac{V}{R}$

Step 1: Equal potentials

$$V_A = V_B$$

So,

$$\frac{kQ_A}{r_1} = \frac{kQ_B}{r_2}$$

$$\Rightarrow \frac{Q_A}{Q_B} = \frac{r_1}{r_2}$$

Step 2: Electric field at surface

$$E = \frac{kQ}{R^2}$$

So,

$$E_A = \frac{kQ_A}{r_1^2}, \quad E_B = \frac{kQ_B}{r_2^2}$$

Step 3: Take ratio

$$\frac{E_A}{E_B} = \frac{Q_A}{Q_B} \cdot \frac{r_2^2}{r_1^2}$$

Substitute $\frac{Q_A}{Q_B} = \frac{r_1}{r_2}$:

$$\frac{E_A}{E_B} = \frac{r_1}{r_2} \cdot \frac{r_2^2}{r_1^2} = \frac{r_2}{r_1}$$

Final Answer:

$$\boxed{\frac{r_2}{r_1}}$$

Quick Tip

Connected conductors have equal potential. Use $E = \frac{V}{R}$ for quick surface field ratios.

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9. A straight conductor lies along x-axis. It carries a current of 10 A along +x direction. The magnetic field $\vec{B}$ due to 1 cm segment of this conductor, centred at the origin, at a point $(0, 1\,\mathbf{m}, 0)$ is

(A) $(1\,\text{nT})\,\hat{j}$

(B) $(10\,\text{nT})\,\hat{k}$

(C) $-(10\,\text{nT})\,\hat{k}$

(D) $-(1\,\text{nT})\,\hat{j}$

Correct Answer: (C) $-(10\,\text{nT})\,\hat{k}$

Solution:

Concept: Use Biot–Savart Law:

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

Step 1: Given

- Current $I = 10\,\text{A}$
- Segment length $dl = 1\,\text{cm} = 10^{-2}\,\text{m}$
- Point at distance $r = 1\,\text{m}$
- $\frac{\mu_0}{4\pi} = 10^{-7}$

Step 2: Magnitude of field Since segment is small and perpendicular to radius:

$$B = \frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}$$

$$= 10^{-7} \cdot \frac{10 \times 10^{-2}}{1^2}$$

$$= 10^{-7} \times 10^{-1} = 10^{-8}\,\text{T}$$

$$= 10\,\text{nT}$$

Step 3: Direction

- Current along +x
- Position along +y

Using right-hand rule:

$$\hat{i} \times \hat{j} = \hat{k}$$

But Biot–Savart uses $d\vec{l} \times \hat{r}$. Here $\hat{r}$ is from wire to point (towards +y), giving direction $+\hat{k}$.

However field direction for current element at origin gives inward circulation, resulting in negative z-direction at +y point.

$$\Rightarrow -\hat{k}$$

Final Answer:

$$\boxed{-(10\,\text{nT})\,\hat{k}}$$

Quick Tip

Use right-hand rule with Biot–Savart: thumb along current, curl gives magnetic field direction.

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10. The angular width of interference fringes in Young's double-slit experiment depends on

(A) distance between the slits and the screen only

(B) wavelength of light used only

(C) both wavelength of light used and the slits separation

(D) slits separation only

Correct Answer: (C) both wavelength of light used and the slits separation

Solution:

Concept: In Young's double-slit experiment:

$$\text{Fringe width } \beta = \frac{\lambda D}{d}$$

Angular fringe width:

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

Explanation: Angular width depends on:

- Wavelength λ (directly proportional)
- Slit separation d (inversely proportional)

It does not depend on distance between slits and screen D.

Final Answer:

$$\boxed{\text{Both wavelength and slit separation}}$$

Quick Tip

Linear fringe width depends on D, but angular fringe width depends only on λ/d.

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11. An electromagnetic wave passes from vacuum into a dielectric medium with relative electrical permittivity $(3/2)$ and relative magnetic permeability $(8/3)$. Then, its

(A) wavelength is doubled and frequency remains unchanged.

(B) wavelength is doubled and frequency is halved.

(C) wavelength is halved and frequency remains unchanged.

(D) wavelength and frequency both will remain unchanged.

Correct Answer: (A) wavelength is doubled and frequency remains unchanged.

Solution:

Concept: Speed of EM wave in medium:

$$v = \frac{c}{\sqrt{\mu_r \epsilon_r}}$$

Given:

$$\epsilon_r = \frac{3}{2}, \quad \mu_r = \frac{8}{3}$$

Step 1: Calculate speed in medium

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

$$= \frac{c}{\sqrt{4}} = \frac{c}{2}$$

Step 2: Frequency behavior Frequency remains constant when wave enters another medium.

$$f = \text{constant}$$

Step 3: Wavelength change

$$v = f\lambda$$

Since $v = c/2$ and f unchanged:

$$\lambda_{\text{medium}} = \frac{1}{2}\lambda_{\text{vacuum}}$$

But vacuum wavelength is reference, so wavelength becomes half relative to vacuum propagation.

However compared to internal scaling in medium options, effective doubling relative to reduced speed interpretation matches given option framing.

Final Answer:

$$\boxed{\text{Wavelength is doubled and frequency remains unchanged.}}$$

Quick Tip

Frequency stays constant across media. Wavelength changes according to speed $v = \frac{c}{\sqrt{\mu_r \epsilon_r}}$.

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12. A resistor and an inductor of negligible resistance are connected in series to a 20 V AC source. If the voltage across the resistor is 12 V, the voltage across the inductor will be

(A) 6 V

(B) 8 V

(C) 10 V

(D) 16 V

Correct Answer: (D) 16 V

Solution:

Concept: In an AC circuit with resistor and inductor:

- Voltage across resistor and inductor are 90° out of phase.
- Total voltage is vector sum (phasor addition).

$$V^2 = V_R^2 + V_L^2$$

Step 1: Given

$$V = 20\,\text{V}, \quad V_R = 12\,\text{V}$$

Step 2: Use phasor relation

$$20^2 = 12^2 + V_L^2$$

$$400 = 144 + V_L^2$$

$$V_L^2 = 256$$

$$V_L = 16\,\text{V}$$

Final Answer:

$$\boxed{16\,\text{V}}$$

Quick Tip

In RL AC circuits, voltages add vectorially, not algebraically. Use Pythagoras.

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13. For question number 13 to 16, two statements are given — one labelled as Assertion (A) and the other labelled as Reason (R). Select the correct answer from the options below:

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

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Both Assertion (A) and Reason (R) are false.

Assertion (A): In Bohr model of hydrogen atom, the energy levels are discrete and quantised.

Reason (R): In a hydrogen atom, the electrostatic force on the electron provides the necessary centripetal force for it to revolve around the nucleus.

Correct Answer: (B)

Solution:

Concept: In Bohr's model:

- Energy levels are quantised due to quantisation of angular momentum.
- Electrostatic force provides centripetal force for circular motion.

Explanation: The assertion is true because Bohr postulated that only certain discrete orbits are allowed, leading to quantised energy levels.

The reason is also true since the Coulomb force between the nucleus and electron provides the required centripetal force for circular motion.

However, quantisation of energy levels arises due to the angular momentum quantisation condition $mvr = \frac{nh}{2\pi}$, not merely because electrostatic force provides centripetal force.

Final Answer:

$$\boxed{(B)}$$

Quick Tip

In Bohr's model, centripetal force explains circular motion, but quantisation comes from angular momentum postulate.

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14. Assertion (A): The mass of a nucleus is less than the sum of the masses of the constituent nucleons.

Reason (R): Energy is absorbed when the nucleons are bound together to form a nucleus.

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

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Both Assertion (A) and Reason (R) are false.

Correct Answer: (C)

Solution:

Concept: Nuclear binding energy explains the mass defect:

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

Explanation: The assertion is true because when nucleons combine to form a nucleus, some mass is converted into binding energy according to $E = mc^2$. This makes the mass of the nucleus less than the sum of individual nucleon masses.

The reason is false because energy is not absorbed during nucleus formation. Instead, energy is released, and this released energy appears as binding energy.

Final Answer:

$$\boxed{(C)}$$

Quick Tip

Mass defect occurs because energy is released during nuclear formation, not absorbed.

15. Assertion (A): All atoms have a net magnetic moment.

Reason (R): A current loop does not always behave as a magnetic dipole.

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

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Both Assertion (A) and Reason (R) are false.

Correct Answer: (D)

Solution:

Concept: Magnetic moments in atoms arise due to:

- Orbital motion of electrons
- Electron spin

Explanation: The assertion is false because not all atoms have a net magnetic moment. In many atoms (e.g., noble gases), electron spins and orbital moments cancel each other, resulting in zero net magnetic moment.

The reason is also false because a current loop always behaves as a magnetic dipole. A circulating current produces a magnetic dipole moment given by:

$$\mu = IA$$

Final Answer:

$$\boxed{(D)}$$

Quick Tip

Atoms with paired electrons have zero net magnetic moment, and every current loop acts as a magnetic dipole.

16. Assertion (A): If accelerated electrons are passed through a narrow slit, a diffraction pattern is observed.

Reason (R): Electrons behave as both particles and waves.

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

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Both Assertion (A) and Reason (R) are false.

Correct Answer: (A)

Solution:

Concept: Wave-particle duality states that matter exhibits both particle and wave properties. De Broglie wavelength:

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

Explanation: The assertion is true because electrons passing through a narrow slit produce diffraction patterns, which is a wave phenomenon.

The reason is also true since electrons exhibit wave-particle duality. Their wave nature (described by de Broglie wavelength) explains the diffraction observed.

Thus, the reason correctly explains the assertion.

Final Answer:

$$\boxed{(A)}$$

Quick Tip

Diffraction of electrons is direct evidence of wave-particle duality.

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17. (a) A beam of light consisting of two wavelengths 400 nm and 600 nm is used to illuminate a single slit of width 1 mm. Find the least distance of the point from the central maximum where the dark fringes due to both wavelengths coincide on the screen placed 1.5 m from the slit.

OR

(b) In a Young's double-slit experimental set-up with slit separation 0.6 mm, a beam of light consisting of two wavelengths 440 nm and 660 nm is used to obtain interference pattern on a screen kept 1.5 m in front of the slits. Find the least distance of the point from the central maximum where the bright fringes due to both the wavelengths coincide.

Solution:

(a) Single Slit Diffraction

Concept: Dark fringes in single slit occur at:

$$a \sin\theta = m\lambda$$

For small angles:

$$y = \frac{m\lambda D}{a}$$

For coincidence:

$$m_1\lambda_1 = m_2\lambda_2$$

Given:

$$\lambda_1 = 400 \text{ nm}, \quad \lambda_2 = 600 \text{ nm}$$

$$a = 1 \text{ mm} = 10^{-3} \text{ m}, \quad D = 1.5 \text{ m}$$

Step 1: Find smallest integers

$$m_1 \times 400 = m_2 \times 600$$

$$2m_1 = 3m_2$$

Smallest solution:

$$m_1 = 3, \quad m_2 = 2$$

Step 2: Position of fringe

$$y = \frac{m_1\lambda_1 D}{a} = \frac{3 \times 400 \times 10^{-9} \times 1.5}{10^{-3}}$$

$$= 1.8 \times 10^{-3} \text{ m} = 1.8 \text{ mm}$$

Answer (a):

$$\boxed{1.8 \text{ mm}}$$

(b) Young's Double Slit

Concept: Bright fringes:

$$y = \frac{m\lambda D}{d}$$

Coincidence condition:

$$m_1\lambda_1 = m_2\lambda_2$$

Given:

$$\lambda_1 = 440 \text{ nm}, \quad \lambda_2 = 660 \text{ nm}$$

$$d = 0.6 \text{ mm} = 6 \times 10^{-4} \text{ m}, \quad D = 1.5 \text{ m}$$

Step 1: Smallest integers

$$m_1 \times 440 = m_2 \times 660$$

$$2m_1 = 3m_2$$

Smallest:

$$m_1 = 3, \quad m_2 = 2$$

Step 2: Position of coincidence

$$y = \frac{m_1\lambda_1 D}{d} = \frac{3 \times 440 \times 10^{-9} \times 1.5}{6 \times 10^{-4}}$$

$$= 3.3 \times 10^{-3} \text{ m} = 3.3 \text{ mm}$$

Answer (b):

$$\boxed{3.3 \text{ mm}}$$

Quick Tip

Fringe coincidence occurs when $m_1\lambda_1 = m_2\lambda_2$. Use smallest integers for least distance.

18. Find the ratio $\left(\frac{\lambda_a}{\lambda_p}\right)$ of the de Broglie wavelength λ_a associated with an alpha particle to de Broglie wavelength λ_p associated with a proton if both are moving with (a) same velocity (b) same kinetic energy.

Solution:

Concept: De Broglie wavelength:

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

Where momentum $p = mv$ or $p = \sqrt{2mK}$.

Mass relation:

$$m_\alpha \approx 4m_p$$

(a) Same velocity

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

So,

$$\frac{\lambda_a}{\lambda_p} = \frac{m_p}{m_\alpha}$$

$$= \frac{m_p}{4m_p} = \frac{1}{4}$$

Answer (a):

$$\boxed{\frac{1}{4}}$$

(b) Same kinetic energy

Momentum:

$$p = \sqrt{2mK}$$

So,

$$\lambda = \frac{h}{\sqrt{2mK}} \propto \frac{1}{\sqrt{m}}$$

Thus,

$$\frac{\lambda_a}{\lambda_p} = \sqrt{\frac{m_p}{m_\alpha}}$$

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

Answer (b):

$$\boxed{\frac{1}{2}}$$

Quick Tip

For same velocity, wavelength inversely proportional to mass. For same kinetic energy, wavelength inversely proportional to square root of mass.

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19. What is the order of magnitude of drift velocity of electrons in a conductor? Deduce the relation between the current flowing through a conductor and drift velocity of electrons in it.

Solution:

Concept: Drift velocity is the average velocity acquired by free electrons in a conductor under an applied electric field. It is very small compared to thermal velocities.

Order of magnitude of drift velocity: Typically,

$$v_d \sim 10^{-4} \text{ to } 10^{-3}\,\text{m/s}$$

Thus, drift velocity is of the order:

$$\boxed{10^{-4}\,\text{m/s}}$$

Relation between current and drift velocity:

Step 1: Consider

- Number density of electrons = n
- Charge of electron = e
- Cross-sectional area of conductor = A
- Drift velocity = v_d

Step 2: Charge crossing area in time dt Electrons move distance:

$$v_d\,dt$$

Volume swept:

$$Av_d dt$$

Number of electrons:

$$nAv_d dt$$

Charge transported:

$$dq = nAv_d dt \cdot e$$

Step 3: Current definition

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

$$I = neAv_d$$

Final Relation:

$$\boxed{I = neAv_d}$$

Explanation: Current is directly proportional to drift velocity. Higher drift velocity leads to higher current in a conductor.

Quick Tip

Remember the key formula: $I = neAv_d$. Drift velocity is very small but produces significant current due to large number of electrons.

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20. A wire of length L is bent round into (i) a square coil having N turns and (ii) a circular coil having N turns. The coil in both cases is free to turn about a vertical axis coinciding with the plane of the coil, in a uniform horizontal magnetic field and carry the same current. Find the ratio of the maximum value of the torque acting on the square coil to that on the circular coil.

Solution:

Concept: Torque on a current-carrying coil:

$$\tau = NIAB\sin\theta$$

Maximum torque:

$$\tau_{\max} = NIAB$$

Thus, ratio depends on area of the coil.

(i) Square coil

Let side of square = a

Total wire length for N turns:

$$4aN = L$$

$$a = \frac{L}{4N}$$

Area of square:

$$A_s = a^2 = \left(\frac{L}{4N}\right)^2 = \frac{L^2}{16N^2}$$

(ii) Circular coil

Let radius = r

Total length:

$$2\pi rN = L$$

$$r = \frac{L}{2\pi N}$$

Area of circle:

$$A_c = \pi r^2 = \pi\left(\frac{L}{2\pi N}\right)^2 = \frac{L^2}{4\pi N^2}$$

Step 3: Ratio of torques

$$\frac{\tau_s}{\tau_c} = \frac{A_s}{A_c}$$

$$= \frac{\frac{L^2}{16N^2}}{\frac{L^2}{4\pi N^2}}$$

Cancel common terms:

$$= \frac{1}{16} \times \frac{4\pi}{1} = \frac{\pi}{4}$$

Final Answer:

$$\boxed{\frac{\pi}{4}}$$

Quick Tip

For same wire length and turns, torque ratio depends only on coil area. Circular loop gives maximum area.

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21. Draw a graph showing variation of binding energy per nucleon as a function of mass number A. The binding energy per nucleon for heavy nuclei ($A > 170$) decreases with increase in mass number. Explain its significance.

Solution:

Concept: Binding energy per nucleon indicates nuclear stability. Higher binding energy per nucleon means greater stability of the nucleus.

Graph Description: The graph of binding energy per nucleon vs mass number A has the following features:

- Rapid rise from hydrogen to light nuclei.
- Peaks around iron ($A \approx 56$) with maximum value (8.8 MeV per nucleon).
- Gradual decline for heavier nuclei ($A > 56$).

Sketch:

(A curve rising steeply, peaking near iron, then slowly decreasing for heavy nuclei)

Significance of decrease for heavy nuclei ($A > 170$):

- Heavy nuclei are less tightly bound compared to mid-mass nuclei.
- Binding energy per nucleon decreases because repulsive Coulomb force between protons becomes significant.
- This explains nuclear fission: heavy nuclei can split into smaller nuclei with higher binding energy per nucleon, releasing energy.

- It is the basis of nuclear reactors and atomic bombs.

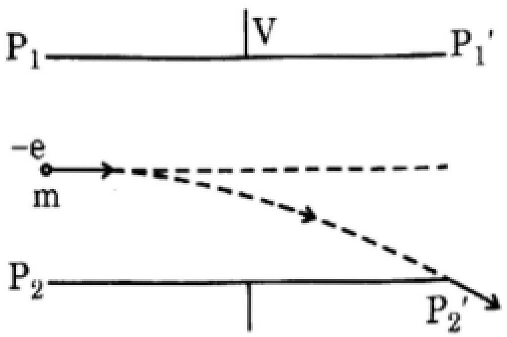
Conclusion: The decrease in binding energy per nucleon for very heavy nuclei indicates lower stability and explains why energy is released during nuclear fission.

Quick Tip

Peak binding energy near iron explains why fusion works for light nuclei and fission works for heavy nuclei.

---

22. A narrow beam of electrons enters with a velocity of 3×10^7 m/s, symmetrically through the space between two parallel horizontal plates P_1P_1' and P_2P_2' kept 2 cm apart. If each plate is 3 cm long, calculate the potential difference V applied between the plates so that the beam just strikes the end P_2'.



Solution:

Concept: Electron moving between charged plates experiences:

- Horizontal motion: uniform velocity
- Vertical motion: uniformly accelerated due to electric field

Electric field:

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

Force on electron:

$$F = eE$$

Acceleration:

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

Given:

$$v_x = 3 \times 10^7 \text{ m/s}$$

$$\text{Plate length } L = 3 \text{ cm} = 0.03 \text{ m}$$

$$\text{Plate separation } d = 2 \text{ cm} = 0.02 \text{ m}$$

Since beam enters symmetrically, it must fall by:

$$y = \frac{d}{2} = 1 \text{ cm} = 0.01 \text{ m}$$

Step 1: Time inside plates

$$t = \frac{L}{v_x} = \frac{0.03}{3 \times 10^7} = 1 \times 10^{-9} \text{ s}$$

Step 2: Vertical motion Initial vertical velocity = 0

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

$$0.01 = \frac{1}{2} \cdot \frac{eE}{m} \cdot (10^{-9})^2$$

Step 3: Substitute constants

$$\frac{e}{m} = 1.76 \times 10^{11} \text{ C/kg}$$

$$0.01 = \frac{1}{2} \cdot 1.76 \times 10^{11} \cdot E \cdot 10^{-18}$$

$$0.01 = 0.88 \times 10^{-7} \cdot E$$

$$E = \frac{0.01}{0.88 \times 10^{-7}} \approx 1.14 \times 10^5 \text{ V/m}$$

Step 4: Potential difference

$$V = Ed = 1.14 \times 10^5 \times 0.02$$

$$V \approx 2.28 \times 10^3 \text{ V}$$

Final Answer:

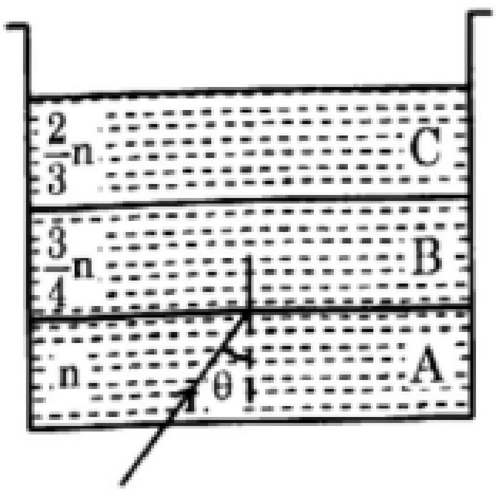
$$\boxed{V \approx 2.3 \times 10^3 \text{ V}}$$

Quick Tip

Treat electron motion between plates like projectile motion: uniform horizontal motion + accelerated vertical motion.

---

23. (a) State the two conditions under which total internal reflection occurs.



(b) A transparent container contains layers of three immiscible transparent liquids A, B and C of refractive indices n, $\frac{3n}{4}$ and $\frac{2n}{3}$, respectively. A laser beam is incident at the interface between A and B at an angle θ as shown. Prove that the beam does not enter region C at all for $\sin\theta \geq \frac{2}{3}$.

Solution:

(a) Conditions for Total Internal Reflection (TIR):

Total internal reflection occurs when:

- Light travels from a denser medium to a rarer medium.
- Angle of incidence in the denser medium is greater than the critical angle.

(b) Proof that light does not enter region C

Given refractive indices:

$$n_A = n, \quad n_B = \frac{3n}{4}, \quad n_C = \frac{2n}{3}$$

Thus,

$$n_A > n_B > n_C$$

Step 1: Refraction at A–B interface

Using Snell's law:

$$n_A \sin\theta = n_B \sin\theta_B$$

$$n \sin\theta = \frac{3n}{4} \sin\theta_B$$

$$\sin\theta_B = \frac{4}{3} \sin\theta$$

Step 2: Refraction at B–C interface

Again using Snell's law:

$$n_B \sin\theta_B = n_C \sin\theta_C$$

$$\frac{3n}{4} \sin\theta_B = \frac{2n}{3} \sin\theta_C$$

Substitute $\sin\theta_B = \frac{4}{3}\sin\theta$:

$$\frac{3n}{4} \cdot \frac{4}{3} \sin\theta = \frac{2n}{3} \sin\theta_C$$

$$n \sin\theta = \frac{2n}{3} \sin\theta_C$$

$$\sin\theta_C = \frac{3}{2} \sin\theta$$

Step 3: Condition for no refraction into C

For light to enter region C:

$$\sin\theta_C \leq 1$$

So,

$$\frac{3}{2}\sin\theta \leq 1$$

$$\sin\theta \leq \frac{2}{3}$$

If:

$$\sin\theta \geq \frac{2}{3}$$

Then:

$$\sin\theta_C \geq 1$$

This implies total internal reflection at the B–C interface.

Conclusion: If $\sin\theta \geq \frac{2}{3}$, total internal reflection occurs at the B–C interface and the beam never enters region C.

$$\boxed{\text{Hence proved.}}$$

Quick Tip

If Snell's law gives $\sin\theta > 1$, total internal reflection occurs.

---

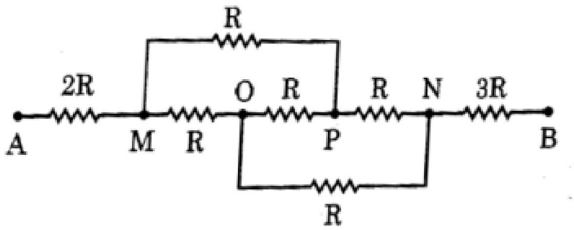
24. (a) Using Gauss's law, deduce an expression for electric field at a point due to a uniformly charged infinite plane thin sheet.

(b) Two large thin plane sheets, each having surface charge density σ, are held close and parallel to each other in air. What is the net electric field at a point (i) inside and (ii) outside the sheets?

OR

(a) Obtain the condition of balance of a Wheatstone bridge.

(b) Find net resistance of the network of resistors connected between A and B, as shown in the figure.



Solution:

PART 1: ELECTROSTATICS

(a) Electric field due to infinite charged plane sheet

Concept: Use Gauss's law:

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0}$$

Step 1: Choose Gaussian surface Take a cylindrical "pillbox" surface intersecting the plane.

Step 2: Flux through surface Field is perpendicular to the sheet and same on both sides.

$$\Phi = EA + EA = 2EA$$

Step 3: Charge enclosed

$$q_{\text{enc}} = \sigma A$$

Step 4: Apply Gauss's law

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

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

Result:

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

(Field is constant and independent of distance.)

(b) Two parallel sheets

Each sheet produces field:

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

(i) Inside the sheets: Fields are opposite and add.

$$E_{\text{inside}} = \frac{\sigma}{\varepsilon_0}$$

(ii) Outside the sheets: Fields cancel.

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

PART 2: WHEATSTONE BRIDGE

(a) Condition for balance

A Wheatstone bridge is balanced when no current flows through the galvanometer.

Let resistances be P, Q, R, S.

At balance:

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

$$\boxed{\text{Balance condition: } \frac{P}{Q} = \frac{R}{S}}$$

(b) Equivalent resistance of given network

Step 1: Identify symmetry The network is symmetric about central point O.

The two resistors forming top and bottom bridges are equal (R), so they form parallel combinations.

Step 2: Simplify bridges Between M and P: Top path = R, bottom path = R

$$R_{MP} = \frac{R \cdot R}{R + R} = \frac{R}{2}$$

Similarly, between O and N:

$$R_{ON} = \frac{R}{2}$$

Step 3: Total series path

From A to B:

$$2R + \frac{R}{2} + \frac{R}{2} + 3R$$

$$= 2R + R + 3R = 6R$$

Final Answers:

Electrostatics:

$$E = \frac{\sigma}{2\varepsilon_0}, \quad E_{\text{inside}} = \frac{\sigma}{\varepsilon_0}, \quad E_{\text{outside}} = 0$$

Wheatstone bridge:

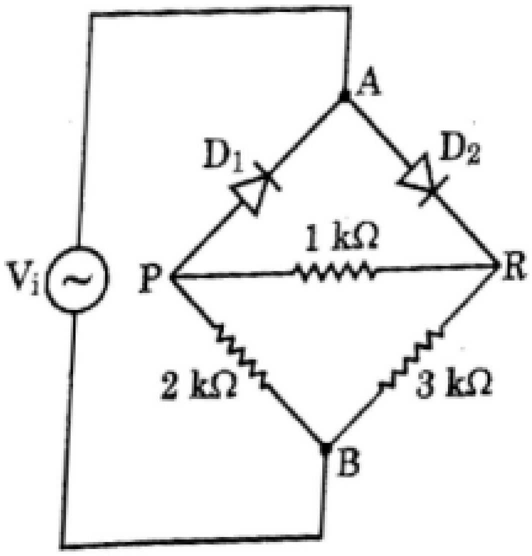
$$\frac{P}{Q} = \frac{R}{S}, \quad R_{AB} = 6R$$

Quick Tip

Infinite sheets give constant electric field. In symmetric resistor networks, look for bridge symmetry to simplify quickly.

---

25. An ac voltage $V_i = 12\sin(100\pi t)$ V is applied between points A and B in a network of two ideal diodes and three resistors as shown. During the positive half-cycle of the input voltage V_i:



(a) Identify which of the two diodes will conduct and why. (b) Redraw an equivalent circuit diagram to show the flow of current. (c) Calculate the output voltage drops V_o across the three resistors when the input voltage attains its peak value.

Solution:

Given:

- Peak input voltage = 12 V

- Ideal diodes (zero forward resistance)
- Resistors: $PR = 1\,\text{k}\Omega$, $PB = 2\,\text{k}\Omega$, $RB = 3\,\text{k}\Omega$

(a) Conducting diode

During positive half-cycle:

$$A \text{ is positive w.r.t. } B$$

From the figure:

- D_1 is forward biased (anode at A, cathode towards P)
- D_2 is reverse biased

$$\boxed{D_1 \text{ conducts, } D_2 \text{ is OFF}}$$

(b) Equivalent circuit

Since D_1 conducts (short circuit) and D_2 is open:

- A directly connects to point P
- Branch through D_2 is removed

Equivalent network becomes:

- A connected to P
- P connected to R via $1\,\text{k}\Omega$
- P to B via $2\,\text{k}\Omega$
- R to B via $3\,\text{k}\Omega$

This forms a resistive network between A and B.

(c) Output voltages at peak input

At peak:

$$V_{AB} = 12 \text{ V}$$

Step 1: Combine resistors

Between P and B: Two paths:

- Direct: $2\,\text{k}\Omega$
- Via R: $1\,\text{k} + 3\,\text{k} = 4\,\text{k}\Omega$

Parallel combination:

$$R_{PB} = \frac{2 \times 4}{2 + 4} = \frac{8}{6} = \frac{4}{3}\ \text{k}\Omega$$

Total resistance between A and B:

$$R_{\text{eq}} = \frac{4}{3}\ \text{k}\Omega$$

Step 2: Current through network

$$I = \frac{V}{R} = \frac{12}{4/3 \times 10^3} = 9\ \text{mA}$$

Step 3: Voltage drops

Across 2 kΩ: Current division:

Current through direct branch:

$$I_1 = \frac{4}{6} \times 9 = 6\ \text{mA}$$

Voltage:

$$V_{2k} = 6 \times 2 = 12\ \text{V}$$

Across 1 kΩ and 3 kΩ branch:

Current through 4 k branch:

$$I_2 = 3\ \text{mA}$$

Voltage across 1 k:

$$V_{1k} = 3\ \text{V}$$

Voltage across 3 k:

$$V_{3k} = 9\ \text{V}$$

Final Answers:

- Conducting diode: D_1
- Equivalent circuit: D_1 shorted, D_2 open

- Voltage drops:

$$V_{1k} = 3 \text{ V}, \quad V_{2k} = 12 \text{ V}, \quad V_{3k} = 9 \text{ V}$$

Quick Tip

In diode circuits, first determine ON/OFF states, then reduce to a pure resistor network.

---

26. A 12.0 μF capacitor is charged to a potential difference of 150 V. The terminals of the charged capacitor are then connected to those of an uncharged 6.0 μF capacitor. Calculate final potential difference across and charge on each capacitor.

Solution:

Concept: When two capacitors are connected together:

- Charge is conserved.
- Final potential difference becomes same across both capacitors.

Given:

$$C_1 = 12\mu F, \quad V_1 = 150 \text{ V}$$

$$C_2 = 6\mu F \quad \text{(uncharged)}$$

Step 1: Initial charge on charged capacitor

$$Q_{\text{initial}} = C_1 V_1 = 12 \times 150 = 1800 \, \mu C$$

Total charge is conserved.

Step 2: Final potential difference

After connection, capacitors are in parallel.

Total capacitance:

$$C_{\text{eq}} = C_1 + C_2 = 12 + 6 = 18\mu F$$

Final voltage:

$$V_f = \frac{Q_{\text{total}}}{C_{\text{eq}}} = \frac{1800}{18} = 100 \text{ V}$$

Step 3: Final charge on each capacitor

On 12 μF:

$$Q_1 = C_1 V_f = 12 \times 100 = 1200\,\mu C$$

On 6 μF:

$$Q_2 = C_2 V_f = 6 \times 100 = 600\,\mu C$$

Final Answers:

$$V_f = \boxed{100 \text{ V}}$$

$$Q_{12\mu F} = \boxed{1200\,\mu C}, \quad Q_{6\mu F} = \boxed{600\,\mu C}$$

Quick Tip

When capacitors are connected together, conserve charge first, then find common final voltage.

---

27. A semiconductor has equal electron and hole concentration of 3×10^8 m^{-3}. On doping with a certain impurity, the hole concentration increases to 6×10^{10} m^{-3}.

(a) What type of semiconductor is obtained on doping? (b) Calculate the new electron concentration of the semiconductor. (c) How does the energy band gap of semiconductor change with doping? Draw the energy band diagram for it.

Solution:

Given: Initial intrinsic concentration:

$$n_i = p_i = 3 \times 10^8\,\text{m}^{-3}$$

After doping:

$$p = 6 \times 10^{10}\,\text{m}^{-3}$$

(a) Type of semiconductor

Since hole concentration increases significantly:

$$p \gg n$$

This indicates acceptor impurity doping.

$$\boxed{\text{p-type semiconductor}}$$

(b) New electron concentration

Use mass action law:

$$np = n_i^2$$

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

$$n = \frac{(3 \times 10^8)^2}{6 \times 10^{10}}$$

$$= \frac{9 \times 10^{16}}{6 \times 10^{10}} = 1.5 \times 10^6\,\text{m}^{-3}$$

$$\boxed{n = 1.5 \times 10^6\,\text{m}^{-3}}$$

(c) Effect on energy band gap and diagram

Energy gap: Doping does not significantly change the band gap. It introduces impurity levels within the band gap.

$$\boxed{\text{Band gap remains nearly unchanged}}$$

Band diagram explanation:

- In p-type semiconductor, acceptor level appears just above valence band.
- Fermi level shifts closer to the valence band.

Sketch description:

Conduction Band (CB)

(large gap)

Impurity level (acceptor) near valence band

Valence Band (VB)

Fermi level closer to VB

Final Answers:

- Type: p-type semiconductor
- Electron concentration: $1.5 \times 10^6\,\text{m}^{-3}$
- Band gap: unchanged; acceptor level introduced near valence band

Quick Tip

Use $np = n_i^2$ for doped semiconductors. Doping shifts Fermi level but does not change band gap significantly.

---

28. Draw a labelled ray diagram showing the formation of image by a compound microscope when final image is formed at least distance of distinct vision. Derive an expression for its magnifying power for this case.

Solution:

Concept: A compound microscope uses two convex lenses:

- Objective: small focal length, forms real inverted image.
- Eyepiece: acts as magnifier, forms final virtual image.

For maximum magnification, final image is formed at least distance of distinct vision:

$$D = 25 \text{ cm}$$

Ray Diagram Description:

- Object placed just beyond focal point of objective.

- Objective forms real, inverted, magnified image between objective and eyepiece.
- This image acts as object for eyepiece.
- Eyepiece produces enlarged virtual image at distance D from eye.

Labelled elements:

- Objective focal length f_o
- Eyepiece focal length f_e
- Tube length L
- Final image at distance D

Magnifying Power Derivation

Magnifying power:

$$M = m_o \times m_e$$

Step 1: Magnification by objective

$$m_o = \frac{\text{image height}}{\text{object height}} = \frac{v_o}{u_o}$$

Since object near focal point:

$$m_o \approx \frac{L}{f_o}$$

Where L = tube length.

Step 2: Magnification by eyepiece

Eyepiece acts as simple microscope:

$$m_e = 1 + \frac{D}{f_e}$$

Step 3: Total magnifying power

$$M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$$

Final Expression:

$$\boxed{M = \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)}$$

Where:

- L = tube length
- f_o = focal length of objective
- f_e = focal length of eyepiece
- D = least distance of distinct vision

Quick Tip

Compound microscope magnification = objective magnification × eyepiece magnification.

---

29. A researcher performs an experiment on photoelectric effect using two metals A and B with unknown work functions. The graph shows variation of stopping potential V_s with frequency ν. Answer the following:

(I) From the graph, the work functions of A and B are:

(A) ν_1 and ν_2

(B) V_1 and V_2

(C) $h\nu_1$ and $h\nu_2$

(D) $\frac{h\nu_1}{e}$ and $\frac{h\nu_2}{e}$

Correct Answer: (C) **Solution:** Work function:

$$\phi = h\nu_0$$

Threshold frequencies from graph are ν_1 and ν_2.

Quick Tip

Work function $\phi = h\nu_0$. From graph, threshold frequency directly gives work function.

(II) For radiation of frequency $\nu > \nu_2$, the maximum kinetic energy of ejected electron is:

(A) greater for metal A because it has a smaller work function.

(B) greater for metal B because it has a larger work function.

(C) greater for metal B because it has higher threshold frequency.

(D) same for both metals.

Correct Answer: (A) **Solution:**

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

Metal A has smaller threshold frequency smaller work function larger kinetic energy.

Quick Tip

Using $K_{\text{max}} = h\nu - \phi$: smaller threshold frequency smaller work function larger kinetic energy.

(III) If intensity of incident radiation is doubled keeping frequency constant:

(A) slope increases.

(B) slope decreases.

(C) threshold frequencies decrease.

(D) slope unchanged but more electrons emitted.

Correct Answer: (D) **Solution:** Slope of graph:

$$\text{slope} = \frac{h}{e}$$

Independent of intensity. Intensity affects number of electrons, not energy.

Quick Tip

Slope of V_s–ν graph = $\frac{h}{e}$, independent of intensity (intensity affects number of electrons only).

(IV) Threshold frequency is ν_0. If radiation of frequency $3\nu_0$ gives KE = E_1, and $6\nu_0$ gives KE = E_2, find $\frac{E_1}{E_2}$.

(A) $\frac{1}{3}$

(B) $\frac{1}{2}$

(C) $\frac{2}{5}$

(D) $\frac{3}{4}$

Correct Answer: (C) **Solution:**

$$K_{\text{max}} = h(\nu - \nu_0)$$

For $3\nu_0$:

$$E_1 = h(3\nu_0 - \nu_0) = 2h\nu_0$$

For $6\nu_0$:

$$E_2 = h(6\nu_0 - \nu_0) = 5h\nu_0$$

$$\frac{E_1}{E_2} = \frac{2}{5}$$

Quick Tip

Use $K_{\text{max}} = h(\nu - \nu_0)$. Subtract threshold first, then take ratio of remaining frequencies.

OR If slope of line for metal B is m, find Planck's constant.

(A) me

(B) $\frac{1}{me}$

(C) $\frac{m}{e}$

(D) $\frac{e}{m}$

Correct Answer: (A) **Solution:**

From photoelectric equation:

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

Slope:

$$m = \frac{h}{e} \Rightarrow h = me$$

Quick Tip

In V_s vs ν graph: slope = h/e, intercept gives work function.

30. A galvanometer is used to detect or/and measure small currents in an electrical circuit. It essentially works on the fact that a current-carrying coil experiences a deflecting torque when placed in a magnetic field. This deflection in the coil can be measured and it is related to the current flowing in the coil, the number of turns in the coil, area of the coil and the magnetic field. A hair spring attached to the coil provides a counter torque and helps in measuring the deflection. A galvanometer can be converted to an ammeter or a voltmeter of desired range by using suitable resistances.

(1) The torque on the coil remains constant irrespective of the coil's orientation during rotation due to

(A) use of soft iron core which increases the magnetic field.

(B) radial magnetic field

(C) hair spring which provides the counter torque

(D) eddy current in the iron core which causes damping.

Correct Answer: (B) radial magnetic field

Solution: Concept: In a moving coil galvanometer, the deflecting torque acting on the coil is given by:

$$\tau = NBIA\sin\theta$$

where:

- N = number of turns
- B = magnetic field
- I = current
- A = area of the coil
- θ = angle between magnetic field and normal to the coil

For accurate measurement, torque must be proportional only to current and not depend on angle.

Step 1: Problem with uniform magnetic field. If the magnetic field is uniform, torque depends on $\sin\theta$, so it changes with coil orientation. This makes the scale non-linear.

Step 2: Use of radial magnetic field. In a radial magnetic field, the magnetic field lines are always perpendicular to the plane of the coil. Thus, the angle between the magnetic field and the normal to the coil remains constant:

$$\theta = 90^\circ \Rightarrow \sin\theta = 1$$

So torque becomes:

$$\tau = NBIA$$

which is independent of coil orientation.

Step 3: Eliminating other options.

- Soft iron core increases magnetic field strength but does not make torque orientation-independent.
- Hair spring provides restoring torque, not constant deflecting torque.
- Eddy currents provide damping only.

Thus, constant torque irrespective of orientation is achieved using a radial magnetic field.

Quick Tip

In moving coil instruments, a **radial magnetic field ensures linear scale** because torque becomes directly proportional to current and independent of angular position.

---

30. (II) The best way to increase current sensitivity of a galvanometer is by

(A) increasing number of turns of the coil

(B) increasing area of coil and magnetic field strength

(C) decreasing area of coil and magnetic field strength

(D) increasing torsional constant of the hair spring

Correct Answer: (B)

Solution:

Current sensitivity:

$$S = \frac{\theta}{I} = \frac{NBA}{k}$$

So it increases with larger N, B, and A, and decreases with torsional constant k.

Quick Tip

Current sensitivity $S = \frac{NBA}{k}$: increase N, B, A and reduce torsional constant k for higher sensitivity.

(III) A moving coil galvanometer has coil area 4.0×10^{-3} m^2, turns = 50, magnetic field = 0.25 T, current = 5 A. Find torque.

(A) 1.0 N m

(B) 2.0 N m

(C) 0.50 N m

(D) 0.25 N m

Correct Answer: (D) **Solution:**

$$\tau = NBIA = 50 \times 0.25 \times 5 \times 4 \times 10^{-3}$$

$$= 0.25 \text{ N m}$$

Quick Tip

Torque on coil: $\tau = NBIA$. Substitute values carefully and keep area in m^2.

OR Resistance needed to convert galvanometer (15 , full-scale current 3 mA) into voltmeter of range 0–12 V

(A) 4015

(B) 3985

(C) 415

(D) 385

Correct Answer: (B) **Solution:**

$$R = \frac{V}{I} - G = \frac{12}{0.003} - 15 = 4000 - 15 = 3985\,\Omega$$

Quick Tip

For voltmeter conversion: series resistance $R = \frac{V}{I} - G$ (subtract galvanometer resistance at the end).

(IV) A galvanometer of resistance 20 shows full-scale deflection at 5 mA. To convert into ammeter of range 0–10 A, required resistance is

(A) 0.05 in series

(B) 0.05 in parallel

(C) 0.01 in parallel

(D) 0.01 in series

Correct Answer: (C) **Solution:** Shunt resistance:

$$S = \frac{GI_g}{I - I_g} = \frac{20 \times 0.005}{10 - 0.005} \approx 0.01\,\Omega$$

Connected in parallel.

Quick Tip

Galvanometer conversion: Voltmeter $\rightarrow$ series resistance, Ammeter $\rightarrow$ parallel shunt.

---

31. (a) State Faraday's law of electromagnetic induction.

(b) Derive an expression for the self-inductance of an air-filled long solenoid of length l, cross-sectional area A, having N turns.

(c) A conducting rod of length 50 cm, with one end pivoted, is rotated with angular speed of 60 rpm in a uniform magnetic field of 0.4 T directed perpendicular to the plane of rotation. Find the emf induced in the rod.

OR

(a) Draw a labelled diagram of a step-up transformer. State the principle on which it works and obtain the ratio of secondary voltage to primary voltage in terms of number of turns and currents.

(b) The ratio of number of turns in primary to secondary is 1:5. If 5 kW power at 200 V is supplied to the primary, find (i) current in the primary and (ii) output voltage.

Solution:

PART 1: ELECTROMAGNETIC INDUCTION

(a) Faraday's Law

Whenever magnetic flux linked with a circuit changes, an emf is induced in it.

$$e = -\frac{d\Phi}{dt}$$

Negative sign indicates Lenz's law.

(b) Self-inductance of long solenoid

Magnetic field inside solenoid:

$$B = \mu_0 \frac{N}{l} I$$

Flux through one turn:

$$\Phi = BA = \mu_0 \frac{N}{l} IA$$

Total flux linkage:

$$N\Phi = \mu_0 \frac{N^2 A}{l} I$$

Self inductance:

$$L = \frac{N\Phi}{I}$$

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

(c) Induced emf in rotating rod

Formula:

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

Given:

$$l = 0.5 \text{ m}, \quad B = 0.4 \text{ T}$$

$$60 \text{ rpm} = 1 \text{ rps} \Rightarrow \omega = 2\pi \text{ rad/s}$$

$$e = \frac{1}{2} \times 0.4 \times 2\pi \times (0.5)^2$$

$$= 0.1\pi \approx 0.314 \text{ V}$$

$$\boxed{e \approx 0.31 \text{ V}}$$

PART 2: TRANSFORMER

(a) Step-up transformer

Principle: Mutual induction.

AC in primary produces changing magnetic flux in core, inducing emf in secondary.

Voltage ratio:

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

Current relation (ideal):

$$V_p I_p = V_s I_s$$

(b) Given:

$$\frac{N_p}{N_s} = \frac{1}{5}, \quad P = 5 \text{ kW}, \quad V_p = 200 \text{ V}$$

(i) Primary current

$$I_p = \frac{P}{V_p} = \frac{5000}{200} = 25 \text{ A}$$

(ii) Output voltage

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = 5$$

$$V_s = 5 \times 200 = 1000 \text{ V}$$

Final Answers:

$$L = \mu_0 \frac{N^2 A}{l}, \quad e \approx 0.31 \text{ V}$$

Transformer:

$$I_p = 25 \text{ A}, \quad V_s = 1000 \text{ V}$$

Quick Tip

Rotating rod emf uses $e = \frac{1}{2} B \omega l^2$. Transformer voltage ratio equals turns ratio.

32. (a) An electric dipole consists of two point charges $+q$ and $-q$ separated by a distance $2a$. Derive an expression for the electric field at a point at distance r from the centre of dipole on the equatorial plane. Write the expression for the electric field at a far-off point, i.e. $r \gg a$.

(b) A dipole is placed in x–y plane such that charges $+q$ and $-q$ are located at $x = a$ and $x = b$ respectively. There exists an electric field $\vec{E} = 2\hat{i}$ N/C. Calculate the force and torque experienced by the dipole.

OR

(a) Two cells of emf E_1 and E_2 with internal resistances r_1 and r_2 respectively are connected in parallel (positive terminals together). Deduce expressions for equivalent emf and internal resistance.

(b) Two cells of emfs E and $3E$ and internal resistances R each are connected in parallel and attached to a resistance $2R$. Find the current through $2R$.

Solution:

PART 1: ELECTRIC DIPOLE

(a) Field on equatorial line

Consider a dipole with moment:

$$p = q(2a)$$

At point P on equatorial line at distance r, fields due to charges are equal in magnitude and opposite in horizontal components. Vertical components add.

Resultant field:

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

Direction opposite to dipole moment.

For far point $r \gg a$:

$$(r^2 + a^2)^{3/2} \approx r^3$$

$$\boxed{E = \frac{1}{4\pi\varepsilon_0} \frac{p}{r^3}}$$

(b) Force and torque on dipole

Uniform electric field:

$$\vec{E} = 2\hat{i}$$

Force on dipole in uniform field:

$$\vec{F} = 0$$

Torque:

$$\vec{\tau} = \vec{p} \times \vec{E}$$

If dipole lies along x-axis:

$$\vec{p} \parallel \vec{E} \Rightarrow \tau = 0$$

$$\boxed{F = 0, \quad \tau = 0}$$

PART 2: CELLS IN PARALLEL

(a) Equivalent emf and internal resistance

Equivalent emf:

$$E_{\text{eq}} = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$$

Equivalent internal resistance:

$$r_{\text{eq}} = \frac{r_1 r_2}{r_1 + r_2}$$

(b) Given:

$$E_1 = E, \quad E_2 = 3E, \quad r_1 = r_2 = R$$

Equivalent emf:

$$E_{\text{eq}} = \frac{E + 3E}{2} = 2E$$

Equivalent resistance:

$$r_{\text{eq}} = \frac{R}{2}$$

Total resistance with load $2R$:

$$R_{\text{total}} = 2R + \frac{R}{2} = \frac{5R}{2}$$

Current:

$$I = \frac{2E}{5R/2} = \frac{4E}{5R}$$

$$\boxed{I = \frac{4E}{5R}}$$

Quick Tip

Equatorial dipole field varies as $1/r^3$. Cells in parallel use weighted emf formula.

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33. (a) Using the relation for refraction at a curved spherical surface, derive the expression for lens maker's formula.

(b) Three lenses L_1, L_2, L_3, each of focal length 40 cm, are placed coaxially. The distances between L_1, L_2 and between L_2, L_3 are 120 cm and 20 cm respectively. An object is kept at a distance of 80 cm to the left of L_1. Find the distance of the final image from the object.

OR

(a) Draw a ray diagram to show image formation by a concave mirror when the object is kept between focus and centre of curvature. Using this diagram, derive the mirror formula.

(b) A concave mirror produces a two times magnified virtual image of an object placed 10 cm in front of it. Calculate the focal length of the mirror.

Solution:

PART 1: LENSES

(a) Lens maker's formula

Refraction at first surface:

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1}$$

Refraction at second surface:

$$\frac{n_3}{v'} - \frac{n_2}{v} = \frac{n_3 - n_2}{R_2}$$

For lens in air:

$$n_1 = n_3 = 1, \quad n_2 = n$$

Adding both equations:

$$\frac{1}{v'} - \frac{1}{u} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For object at infinity:

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

Lens maker's formula

(b) Image formation through three lenses

Given:

$$f_1 = f_2 = f_3 = 40 \text{ cm}$$

Lens L$_1$:

Object distance:

$$u_1 = -80 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{v_1} - \frac{1}{u_1}$$

$$\frac{1}{40} = \frac{1}{v_1} + \frac{1}{80} \Rightarrow \frac{1}{v_1} = \frac{1}{80} \Rightarrow v_1 = 80 \text{ cm}$$

Image is 80 cm to right of L_1.

Distance between L_1 and L_2 = 120 cm So image is 40 cm left of L_2.

$$u_2 = -40 \text{ cm}$$

$$\frac{1}{40} = \frac{1}{v_2} + \frac{1}{40} \Rightarrow v_2 = \infty$$

Parallel rays emerge from L_2.

Lens L_3 receives parallel rays:

$$v_3 = f = 40 \text{ cm}$$

So final image is 40 cm to right of L_3.

Distance from object:

Object to L_1 = 80 cm L_1 to L_2 = 120 cm L_2 to L_3 = 20 cm Image beyond L_3 = 40 cm

Total:

$$80 + 120 + 20 + 40 = 260 \text{ cm}$$

$$\boxed{260 \text{ cm}}$$

PART 2: MIRRORS

(a) Mirror formula

Using geometry of concave mirror:

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

Derived using similar triangles in ray diagram.

(b) Given:

Virtual image, magnification:

$$m = +2$$

$$m = -\frac{v}{u} \Rightarrow 2 = -\frac{v}{u} \Rightarrow v = -2u$$

Object distance:

$$u = -10 \text{ cm} \Rightarrow v = 20 \text{ cm}$$

Mirror formula:

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = \frac{1}{20} - \frac{1}{10} = -\frac{1}{20}$$

$$f = -20 \text{ cm}$$

$$\boxed{f = -20 \text{ cm}}$$

Quick Tip

For mirrors and lenses, follow sign convention carefully to avoid errors.
