CBSE Class 12 Physics (55/2/1) 2024 Question Paper with Solutions

Time Allowed : 3 Hours	**Maximum Marks :** 70	**Total Questions :** 33

General Instructions

Read the following instructions very carefully and strictly follow them:

1. (i) This question paper contains 33 questions. All questions are compulsory.
2. (ii) This question paper is divided into five sections Sections A, B, C, D and E.
3. (iii) In Section A Questions no. 1 to 16 are Multiple Choice type questions. Each question carries 1 mark.
4. (iv) In Section B Questions no. 17 to 21 are Very Short Answer type questions.Each question carries 2 marks.
5. (v) In Section C Questions no. 22 to 28 are Short Answer type questions. Each question carries 3 marks.
6. (vi) In Section D Questions no. 29 and 30 are case study based questions. Each question carries 4 marks.
7. (vii) In Section E Questions no. 31 to 33 are Long Answer type questions. Each question carries 5 marks.
8. (viii) There is no overall choice given in the question paper. However, an internal choice has been provided in few questions in all the Sections except Section A.
9. (ix) Kindly note that there is a separate question paper for Visually Impaired candidates.
10. (x) Use of calculators is not allowed.

Section A

1. Two charged particles P and Q, having the same charge but different masses m_p and m_q, start from rest and travel equal distances in a uniform electric field $\vec{E}$ in time t_P and t_Q respectively. Neglecting the effect of gravity, the ratio $\frac{t_P}{t_Q}$ is:

(A) $\frac{m_P}{m_Q}$

(B) $\frac{m_Q}{m_P}$

(C) $\frac{\sqrt{m_P}}{\sqrt{m_Q}}$

(D) $\frac{m_Q}{\sqrt{m_P}}$

Correct Answer: (C) $\frac{\sqrt{m_P}}{\sqrt{m_Q}}$

Solution:

Step 1: Since both particles start from rest and travel equal distances in the same electric field, we can use the equation of motion under constant acceleration. The force on each particle due to the electric field is:

$$F_P = qE \quad \text{and} \quad F_Q = qE$$

where q is the charge (same for both particles). The acceleration of each particle is given by:

$$a_P = \frac{F_P}{m_p} = \frac{qE}{m_p} \quad \text{and} \quad a_Q = \frac{F_Q}{m_q} = \frac{qE}{m_q}$$

The distance travelled by each particle is related to acceleration and time by the equation:

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

Since the distances are equal for both particles, we have:

$$\frac{1}{2}a_P t_P^2 = \frac{1}{2}a_Q t_Q^2$$

Simplifying, we get:

$$a_P t_P^2 = a_Q t_Q^2 \quad \Rightarrow \quad \frac{qE}{m_p}t_P^2 = \frac{qE}{m_q}t_Q^2$$

Canceling out common terms and simplifying further:

$$\frac{t_P^2}{t_Q^2} = \frac{m_q}{m_p} \quad \Rightarrow \quad \frac{t_P}{t_Q} = \frac{\sqrt{m_p}}{\sqrt{m_q}}$$

> **Quick Tip**
>
> For objects moving in a uniform electric field with the same charge, the time taken to travel equal distances depends on their masses. The ratio of the times taken can be found using the relationship between acceleration and mass.

Question 2: Electrons drift with speed v_d in a conductor with potential difference V across its ends. If V is reduced to $\frac{V}{2}$, their drift speed will become:

(A) $\frac{v_d}{2}$
(B) v_d
(C) $2v_d$
(D) $4v_d$

Correct Answer: (A) $\frac{v_d}{2}$

Solution:
The drift speed v_d of electrons is given by:

$$v_d = \mu \cdot E$$

where μ is the mobility of the electrons and E is the electric field. The electric field E is directly proportional to the potential difference V, i.e.,

$$E \propto V$$

If V is reduced to $\frac{V}{2}$, then:

$$E_{\text{new}} = \frac{E}{2}$$

Therefore, the new drift speed is:

$$v_{d,\text{new}} = \mu \cdot \frac{E}{2} = \frac{v_d}{2}$$

Thus, the correct answer is **(A)** $\frac{v_d}{2}$.

> **Quick Tip**
>
> The drift speed of electrons in a conductor is directly proportional to the applied potential difference.

Question 3: A wire of length 4.4 m is bent round in the shape of a circular loop and carries a current of 1.0 A. The magnetic moment of the loop will be:
(A) $0.7\,\text{Am}^2$
(B) $1.54\,\text{Am}^2$
(C) $2.10\,\text{Am}^2$
(D) $3.5\,\text{Am}^2$

Correct Answer: (B) $1.54\,\mathbf{Am}^2$

Solution:
The magnetic moment of a current-carrying loop is given by:

$$M = I \cdot A$$

where:

- I is the current flowing through the loop.
- A is the area of the loop.

The wire is bent into the shape of a circular loop. The circumference of the loop is equal to the length of the wire, i.e.,

$$\text{Circumference} = 2\pi r = 4.4\,\text{m}$$

From this, the radius of the loop is:

$$r = \frac{4.4}{2\pi} = \frac{4.4}{6.28} = 0.7\,\text{m}$$

The area of the loop is:

$$A = \pi r^2 = \pi (0.7)^2 = 3.14 \cdot 0.49 = 1.54\,\text{m}^2$$

Substituting the values of I and A into the formula for M:

$$M = 1.0 \cdot 1.54 = 1.54\,\text{Am}^2$$

Thus, the correct answer is **(B)** $1.54\,\mathbf{Am}^2$.

> 💡 Quick Tip
>
> The magnetic moment of a current-carrying loop depends on the current and the area of the loop. For a wire bent into a circle, use the circumference to calculate the radius and then the area.

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4. A circular coil of radius 10 cm is placed in a magnetic field $\vec{B} = (1.0\hat{\imath} + 0.5\hat{\jmath})$ mT such that the outward unit vector normal to the surface of the coil is $(0.6\hat{\imath} + 0.8\hat{\jmath})$. The magnetic flux linked with the coil is:

(A) 0.314 µWb
(B) 3.14 µWb
(C) 31.4 µWb
(D) 1.256 µWb

Correct Answer: (C) 31.4 µWb

Solution:

Step 1: The magnetic flux Φ linked with a coil is given by:

$$\Phi = BA\cos\theta$$

where: - B is the magnetic field, - A is the area of the coil, - θ is the angle between the magnetic field and the normal to the surface of the coil.

Step 2: The area A of the circular coil is given by:

$$A = \pi r^2 = \pi(0.1)^2 = 0.0314\,\mathrm{m}^2$$

Step 3: The unit normal vector to the surface is $(0.6\hat{\imath} + 0.8\hat{\jmath})$, and the magnetic field is $(1.0\hat{\imath} + 0.5\hat{\jmath})$ mT. The angle θ is the angle between the vectors $\vec{B}$ and $\hat{n}$, which is given by the dot product formula:

$$\cos\theta = \frac{\vec{B}\cdot\hat{n}}{|\vec{B}||\hat{n}|}$$

Substituting the values:

$$\vec{B}\cdot\hat{n} = (1.0\cdot 0.6 + 0.5\cdot 0.8) = 0.6 + 0.4 = 1.0$$

$$|\vec{B}| = \sqrt{1.0^2 + 0.5^2} = \sqrt{1.25} \approx 1.118\,\mathrm{mT}$$

$$|\hat{n}| = 1$$

Thus,

$$\cos\theta = \frac{1.0}{1.118} \approx 0.894$$

Step 4: The magnetic flux is then:

$$\Phi = BA\cos\theta = (1.118\times 10^{-3}\,\mathrm{T})\times(0.0314\,\mathrm{m}^2)\times 0.894$$

$$\Phi \approx 3.14\times 10^{-5}\,\mathrm{Wb} = 31.4\,\mu\mathrm{Wb}$$

💡 Quick Tip

To calculate magnetic flux, remember to use the formula $\Phi = BA\cos\theta$, and always check the units of B, A, and $\cos\theta$ to ensure consistency.

Question 5: Which of the following quantity/quantities remain the same in primary and secondary coils of an ideal transformer?
Current, Voltage, Power, Magnetic flux
(A) Current only
(B) Voltage only
(C) Power only
(D) Magnetic flux and Power both

Correct Answer: (D) Magnetic flux and Power both

Solution:
In an ideal transformer:

- The magnetic flux linking the primary and secondary coils is the same since the coils share a common core.
- Power remains conserved, as the energy is transferred efficiently without losses.
- However, current and voltage vary depending on the number of turns in the primary and secondary coils as per the transformer equation.

Thus, the correct answer is **(D) Magnetic flux and Power both**.

💡 Quick Tip

For an ideal transformer, flux linkage and power remain constant, while current and voltage depend on the turns ratio.

Question 6: A resistor and an ideal inductor are connected in series to a $100\sqrt{2}\,$V, $50\,$Hz AC source. When a voltmeter is connected across the resistor or the inductor, it shows the same reading. The reading of the voltmeter is:
(A) $100\sqrt{2}\,$V
(B) $100\,$V
(C) $50\sqrt{2}\,$V
(D) $50\,$V

Correct Answer: (B) $100\,$**V**

Solution:

The source voltage is given as $V_s = 100\sqrt{2}\,\text{V}$. Since the voltmeter shows the same reading across the resistor and the inductor, the voltage across each component must be equal in magnitude. In a series R-L circuit, the source voltage is divided equally between the resistor and the inductor due to their equal impedance. Therefore:

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

Thus, the voltmeter reads **(B)** $100\,\mathbf{V}$.

> Quick Tip
>
> For an R-L circuit with equal voltage readings across the resistor and inductor, the source voltage is divided equally, indicating impedance symmetry.

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7. Electromagnetic waves with wavelength 10 nm are called:
(A) Infrared waves
(B) Ultraviolet rays
(C) Gamma rays
(D) X-rays
Correct Answer: (B) Ultraviolet rays
Solution:
Electromagnetic waves are classified according to their wavelengths. The electromagnetic spectrum includes a range of waves, such as:

- **Infrared waves**: Wavelengths from $700\,\text{nm}$ to $1\,\text{mm}$.

- **Ultraviolet rays**: Wavelengths from about $10\,\text{nm}$ to $400\,\text{nm}$.

- **X-rays**: Wavelengths from about $0.01\,\text{nm}$ to $10\,\text{nm}$.

- **Gamma rays**: Wavelengths shorter than $0.01\,\text{nm}$.

Given that the wavelength is $10\,\text{nm}$, it falls within the **Ultraviolet ray** range, so the correct answer is **(B) Ultraviolet rays**.

> Quick Tip
>
> Electromagnetic waves with wavelengths between $10\,\text{nm}$ and $400\,\text{nm}$ are classified as ultraviolet rays. This range includes a wide variety of applications, such as sterilization and fluorescence.

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8. The work function for a photosensitive surface is 3.315 eV. The cut-off wavelength for photoemission of electrons from this surface is:

(A) 150 nm
(B) 200 nm
(C) 375 nm
(D) 500 nm
Correct Answer: (C) 375 nm
Solution:
The photoelectric equation is given by:

$$E_k = h\nu - \phi$$

where: - E_k is the kinetic energy of the emitted electron, - h is Planck's constant, - ν is the frequency of the incident light, - ϕ is the work function.
At the cut-off wavelength, the kinetic energy E_k of the emitted electron is zero. Therefore, the energy of the photon E is equal to the work function ϕ:

$$E = \phi = h\nu$$

The frequency ν is related to the wavelength λ by:

$$\nu = \frac{c}{\lambda}$$

Substituting this into the equation, we get:

$$\phi = h\frac{c}{\lambda}$$

Rearranging for λ:

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

Now, substituting the known values: - $h = 6.626 \times 10^{-34}\,\text{J·s}$, - $c = 3.0 \times 10^8\,\text{m/s}$, - $\phi = 3.315\,\text{eV} = 3.315 \times 1.602 \times 10^{-19}\,\text{J}$,

$$\lambda = \frac{6.626 \times 10^{-34} \times 3.0 \times 10^8}{3.315 \times 1.602 \times 10^{-19}} \approx 375\,\text{nm}$$

Thus, the cut-off wavelength is $\lambda = 375\,\text{nm}$.

Quick Tip

For calculating the cut-off wavelength for photoemission, use the equation:

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

where h is Planck's constant, c is the speed of light, and ϕ is the work function in joules.

Question 9: Energy levels A, B, and C of an atom correspond to increasing values of energy, i.e., $E_A < E_B < E_C$. Let λ_1, λ_2, and λ_3 be the wavelengths of radiation corresponding to the transitions C to B, B to A, and C to A, respectively. The correct relation between λ_1, λ_2, and λ_3 is:

(A) $\lambda_1^2 + \lambda_2^2 = \lambda_3^2$
(B) $\frac{1}{\lambda_1} + \frac{1}{\lambda_2} = \frac{1}{\lambda_3}$
(C) $\lambda_1 + \lambda_2 + \lambda_3 = 0$
(D) $\lambda_1 + \lambda_2 = \lambda_3$

Correct Answer: (B) $\frac{1}{\lambda_1} + \frac{1}{\lambda_2} = \frac{1}{\lambda_3}$

Solution:
The energy associated with a photon is inversely proportional to its wavelength:

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

For the transitions, the following energy relations hold:

$$E_C - E_B = \frac{hc}{\lambda_1}, \quad E_B - E_A = \frac{hc}{\lambda_2}, \quad \text{and} \quad E_C - E_A = \frac{hc}{\lambda_3}.$$

From the above,

$$(E_C - E_B) + (E_B - E_A) = E_C - E_A.$$

Substituting the expressions for energy:

$$\frac{hc}{\lambda_1} + \frac{hc}{\lambda_2} = \frac{hc}{\lambda_3}.$$

Simplifying:

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

Thus, the correct relation is:

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

Quick Tip

The wavelengths of the radiation emitted in transitions between energy levels in an atom are related by the sum of the individual energy differences. The sum of the inverse of the wavelengths of individual transitions equals the inverse of the wavelength of the total transition.

Question 10: An alpha particle approaches a gold nucleus in the Geiger-Marsden experiment with kinetic energy K. It momentarily stops at a distance d from the nucleus and reverses its direction. Then d is proportional to:
(A) $\frac{1}{\sqrt{K}}$
(B) $\sqrt{K}$
(C) $\frac{1}{K}$
(D) K

Correct Answer: (C) $\frac{1}{K}$

Solution:

The distance of closest approach d in a Rutherford scattering experiment is determined by equating the initial kinetic energy of the alpha particle to the electrostatic potential energy at the closest point:

$$K = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{d}.$$

Rearranging for d:

$$d = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{K}.$$

From this, we see that d is inversely proportional to K, i.e.:

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

Thus, the correct answer is:

$$\boxed{\frac{1}{K}}.$$

> 💡 Quick Tip
>
> The distance at which an alpha particle momentarily stops and reverses direction is inversely proportional to its kinetic energy. This is due to the conservation of energy, where the kinetic energy is converted into electrostatic potential energy.

Question 11: An n-type semiconducting Si is obtained by doping intrinsic Si with:

(A) Al

(B) B

(C) P

(D) In

Correct Answer: (C) P

Solution:

An n-type semiconductor is formed by doping silicon (Si) with a pentavalent impurity. Phosphorus (P) is a pentavalent element, which donates extra electrons, thereby increasing the number of negative charge carriers in the silicon lattice.

Other elements such as aluminum (Al), boron (B), and indium (In) are trivalent and create p-type semiconductors instead by increasing the number of holes.

Thus, the correct answer is:

$$\boxed{\text{P}}.$$

> 💡 Quick Tip
>
> To create an n-type semiconductor, use pentavalent dopants (e.g., P, As, Sb). To create a p-type semiconductor, use trivalent dopants (e.g., B, Al, In).

Question 12: When a p-n junction diode is subjected to reverse biasing:
(A) The barrier height decreases and the depletion region widens.
(B) The barrier height increases and the depletion region widens.
(C) The barrier height decreases and the depletion region shrinks.
(D) The barrier height increases and the depletion region shrinks.

Correct Answer: (B) The barrier height increases and the depletion region widens.

Solution:
When a p-n junction diode is reverse biased, the following effects are observed:
- The reverse bias increases the potential difference across the p-n junction.
- This causes an increase in the barrier height (the potential barrier at the junction becomes stronger).
- The reverse bias also widens the depletion region as the immobile charge carriers in the junction are further separated.

This occurs because the reverse bias pulls majority carriers away from the junction, increasing the width of the depletion region and the strength of the electric field across it.

Thus, the correct answer is:

$$\boxed{\text{The barrier height increases and the depletion region widens.}}$$

Quick Tip

In reverse bias, the depletion region widens, and the junction acts as an insulator, preventing the flow of majority carriers. This property is utilized in devices like photodiodes and Zener diodes.

Questions number 13 to 16 are Assertion (A) and Reason (R) type questions. Two statements are given one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer from the codes (A), (B), (C) and (D) as given below.
(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).
(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the Assertion (A).
(C) Assertion (A) is true, but Reason (R) is false.
(D) Assertion (A) is false and Reason (R) is also false.

Question 13: Assertion and Reason type question.
Assertion (A): Photoelectric current increases with an increase in intensity of incident radiation, for a given frequency of incident radiation and the accelerating potential.

Reason (R): Increase in the intensity of incident radiation results in an increase in the number of photoelectrons emitted per second and hence an increase in the photocurrent.

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

Solution:
The photoelectric current is directly proportional to the intensity of incident radiation. This is because the intensity of radiation determines the number of photons incident on the surface per second. An increase in intensity implies a larger number of photons, which in turn increases the number of photoelectrons emitted, thereby increasing the photocurrent. Hence, both the Assertion (A) and Reason (R) are true, and Reason (R) correctly explains Assertion (A).

> Quick Tip
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> Remember, the intensity of incident radiation affects the number of emitted photoelectrons, not their kinetic energy, which is governed by the frequency of the radiation as per Einstein's photoelectric equation.

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14. Assertion (A): Lenz's law is a consequence of the law of conservation of energy.
Reason (R): There is no power loss in an ideal inductor.

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

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

Solution: Lenz's law states that the direction of an induced current is such that it opposes the change in magnetic flux that caused it. This law is a direct consequence of the **law of conservation of energy**, as it ensures that the energy supplied by the induced current is used to oppose the cause of its creation. Therefore, **Assertion (A)** is true.

Reason (R): In an ideal inductor, there is no energy loss due to resistance, which means no power is dissipated. However, the lack of power loss does not directly explain Lenz's law. The principle behind Lenz's law relates to the conservation of energy, while the behavior of an ideal inductor is more concerned with the absence of resistive losses.

Thus, while both the assertion and the reason are true, the reason does not correctly explain the assertion. Therefore, the correct answer is **(B)**.

Quick Tip

Lenz's law is based on the principle of conservation of energy. It ensures that the induced current always works in a way that opposes the change in magnetic flux, which aligns with the energy conservation law.

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15. Assertion (A): An electron and a proton enter with the same momentum $\vec{p}$ in a magnetic field $\vec{B}$ such that $\vec{p} \perp \vec{B}$. Then both describe a circular path of the same radius. Reason (R): The radius of the circular path described by the charged particle (charge q, mass m) moving in the magnetic field $\vec{B}$ is given by $r = \frac{mv}{qB}$.

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

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

Solution: The magnetic force acting on a charged particle moving perpendicular to a magnetic field is given by:

$$F = qvB$$

This force provides the centripetal force necessary to move the particle in a circular path. Therefore, the radius of the circular path is given by the relation:

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

where: - m is the mass of the particle, - v is the speed of the particle, - q is the charge of the particle, - B is the magnetic field strength.

Since the electron and proton enter with the same momentum $\vec{p} = mv$, and they have different masses (m_e and m_p), we can conclude that the ratio of their radii is determined by their mass and charge. The assertion states that both the electron and proton describe a circular path of the same radius, which is true when both particles have the same momentum and the same charge-to-mass ratio.

Thus, **Assertion (A)** is true, and **Reason (R)** provides the correct explanation for **Assertion (A)**, as it correctly describes the relationship between mass, charge, and radius in the magnetic field.

Quick Tip

The radius of the circular path of a charged particle in a magnetic field depends on the particle's momentum, charge, and the magnetic field strength. If two particles have the same momentum and charge-to-mass ratio, they will describe circular paths of the same radius.

Question 16:Assertion and Reason type question.
Assertion (A): The magnifying power of a compound microscope is negative.
Reason (R): The final image formed is erect with respect to the object.

Correct Answer: (D) Assertion (A) is false and Reason (R) is also false.

Solution:
The magnifying power of a compound microscope is always positive, as it is a measure of how much larger the image appears compared to the object. The final image formed by a compound microscope is inverted with respect to the object, not erect. Therefore, both Assertion (A) and Reason (R) are false.

> Quick Tip
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> The sign of magnification depends on whether the image is inverted or erect. For optical devices like microscopes and telescopes, an inverted image corresponds to negative magnification, but the magnifying power itself is always positive.

SECTION B

Question 17: Define resistivity of a conductor. How does the resistivity of a conductor depend upon the following:
(a) Number density of free electrons in the conductor (n)
(b) Their relaxation time (τ)

Solution:
Definition of Resistivity:
Resistivity (ρ) of a conductor is a material property that quantifies how strongly the material opposes the flow of electric current. It is defined as the resistance offered by a conductor of unit length and unit cross-sectional area. Mathematically:

$$\rho = R \cdot \frac{A}{l}$$

where R is the resistance, A is the cross-sectional area, and l is the length of the conductor. Its SI unit is $\Omega\,\mathrm{m}$.

Dependence of Resistivity on n and τ:
1. **Dependence on n (Number Density of Free Electrons):**
Resistivity is inversely proportional to the number density of free electrons in the conductor. The relation is given by:

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

where m is the mass of an electron, e is the charge of an electron, and τ is the relaxation time. Thus, as n increases, the resistivity ρ decreases because the availability of more free electrons reduces the opposition to current flow.
2. **Dependence on τ (Relaxation Time):**
Relaxation time (τ) is the average time between successive collisions of an electron with the

lattice ions. Resistivity is inversely proportional to the relaxation time. Mathematically:

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

As τ increases, the resistivity ρ decreases because longer relaxation times mean fewer collisions, leading to less opposition to current flow.

> Quick Tip
>
> Resistivity is a fundamental property of materials and depends not only on the material itself but also on temperature, impurities, and physical conditions. Increasing the number density (n) or relaxation time (τ) will reduce resistivity and enhance conductivity.

Question 18:
(a) Two waves, each of amplitude a and frequency ω emanating from two coherent sources of light superpose at a point. If the phase difference between the two waves is ϕ, obtain an expression for the resultant intensity at that point.
OR
(b) What is the effect on the interference pattern in Young's double-slit experiment when: (i) the source slit is moved closer to the plane of the slits, and
(ii) the separation between the two slits is increased? Justify your answers.

Solution:
(a) **Resultant Intensity at a Point:**
The displacement due to two coherent waves at a point is given by:

$$y_1 = a\sin\omega t \quad \text{and} \quad y_2 = a\sin(\omega t + \phi)$$

Using the principle of superposition, the resultant displacement is:

$$y = y_1 + y_2 = a\sin\omega t + a\sin(\omega t + \phi)$$

Using the trigonometric identity:

$$\sin A + \sin B = 2\sin\left(\frac{A+B}{2}\right)\cos\left(\frac{A-B}{2}\right),$$

we get:

$$y = 2a\cos\left(\frac{\phi}{2}\right)\sin\left(\omega t + \frac{\phi}{2}\right).$$

The resultant amplitude is:

$$A = 2a\cos\left(\frac{\phi}{2}\right).$$

The intensity is proportional to the square of the amplitude:

$$I = A^2 \propto \left[2a\cos\left(\frac{\phi}{2}\right)\right]^2 = 4a^2\cos^2\left(\frac{\phi}{2}\right).$$

Thus, the resultant intensity at the point is:

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

where I_0 is the intensity of each wave.

OR

(b) **Effect on Interference Pattern:**

(i) **When the source slit is moved closer to the plane of the slits:**

The fringe width (β) is given by:

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

where λ is the wavelength of light, D is the distance between the source slit and the plane of the slits, and d is the separation between the slits. If D decreases, the fringe width β decreases, causing the fringes to get closer and become less distinct.

(ii) **When the separation between the two slits (d) is increased:**

From the same formula, as d increases, the fringe width β decreases. This results in narrower fringes, increasing the fringe density in the interference pattern.

> Quick Tip
>
> The intensity in an interference pattern depends on the phase difference between the waves, while the fringe width depends on the geometry of the experimental setup.

Question 19:

A convex lens ($n = 1.52$) has a focal length of 15.0 cm in air. Find its focal length when it is immersed in a liquid of refractive index 1.65. What will be the nature of the lens?

Solution:

Finding the Focal Length Nature of the Lens

For a convex lens in air:

$$\frac{1}{f_a} = \left(\frac{n_a - 1}{n_a}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For a convex lens in a liquid:

$$\frac{1}{f_l} = \left(\frac{n_l - 1}{n_l}\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Given: $n = 1.52$ (refractive index of the lens material), $n_l = 1.65$ (refractive index of the liquid).
By substituting the values:

$$\frac{f_l}{f_a} = \frac{1}{1.52 - 1.65}$$

$$\frac{f_l}{f_a} = -6.6 \quad \Rightarrow \quad f_l = -99\,\text{cm}$$

Nature of the Lens: The lens behaves like a **diverging** lens or a **concave lens** in the liquid.

> Quick Tip
>
> A lens that is converging in air (convex) can become diverging (concave) in a medium with a higher refractive index than the lens.

Question 20:
The carbon isotope $^{12}_{6}C$ has a nuclear mass of $12.000000\,\mathbf{u}$. Calculate the binding energy of its nucleus.
Given:
$m_p = 1.007825\,\mathbf{u}$, $m_n = 1.008665\,\mathbf{u}$.

Solution:
The binding energy of a nucleus can be calculated using the mass defect Δm and Einstein's equation:

$$E_b = \Delta m\, c^2,$$

where Δm is the difference between the mass of the nucleus and the sum of the masses of its nucleons.
Step 1: Calculate the total mass of nucleons: The nucleus of $^{12}_{6}C$ has 6 protons and 6 neutrons. Therefore:

$$\text{Mass of nucleons} = 6m_p + 6m_n.$$

Substitute the given values:

$$\text{Mass of nucleons} = 6(1.007825) + 6(1.008665)\,\text{u}.$$

$$\text{Mass of nucleons} = 6.04695 + 6.05199 = 12.09894\,\text{u}.$$

Step 2: Calculate the mass defect: The mass defect Δm is:

$$\Delta m = \text{Mass of nucleons} - \text{Nuclear mass}.$$

Substitute the values:

$$\Delta m = 12.09894 - 12.000000 = 0.09894\,\text{u}.$$

Step 3: Convert mass defect to energy: Using $1\,\text{u} = 931.5\,\text{MeV/c}^2$:

$$E_b = \Delta m \times 931.5.$$

$$E_b = 0.09894 \times 931.5 = 92.18\,\text{MeV}.$$

Final Answer: The binding energy of the $^{12}_{6}C$ nucleus is:

$$\boxed{92.18\,\text{MeV}}.$$

Quick Tip

Binding energy is a measure of the stability of a nucleus. Higher binding energy per nucleon indicates a more stable nucleus.

Question 21:
How does the energy gap of an intrinsic semiconductor effectively change when doped with (a) a trivalent impurity, and (b) a pentavalent impurity? Justify your answer in each case.

Solution:
(a) Trivalent impurity:
Doping an intrinsic semiconductor with a trivalent impurity (e.g., boron in silicon) creates **acceptor energy levels** just above the valence band. These energy levels are very close to the valence band, reducing the energy required for electrons to transition from the valence band to the acceptor levels. As a result, the effective energy gap for conduction reduces slightly, as the transition involves a smaller energy difference.

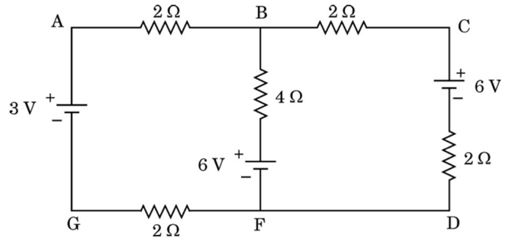
(b) Pentavalent impurity:
Doping with a pentavalent impurity (e.g., phosphorus in silicon) introduces **donor energy levels** just below the conduction band. Electrons from the donor levels require very little energy to jump into the conduction band. Therefore, the effective energy gap for conduction reduces slightly, as the transition involves a smaller energy difference.

Conclusion: Doping with trivalent or pentavalent impurities effectively reduces the energy gap of an intrinsic semiconductor for conduction, enabling easier flow of charge carriers (holes or electrons).

Quick Tip

Doping changes the electrical properties of semiconductors by introducing impurity energy levels within the band gap, reducing the energy required for conduction.

SECTION C
Question 22:
The figure shows a circuit with three ideal batteries. Find the magnitude and direction of currents in the branches AG, BF, and CD.



Solution:
To solve this circuit, we will use Kirchhoff's Voltage Law (KVL) and Kirchhoff's Current Law (KCL).

Step 1: Assign currents and directions: Let the currents in the branches be as follows:

$$I_1 \text{ in branch AG}, \quad I_2 \text{ in branch BF}, \quad \text{and } I_3 \text{ in branch CD}.$$

Assume the direction of all currents as clockwise. The actual direction will be determined by the solution.

Step 2: Apply Kirchhoff's Current Law (KCL) at node B: At node B, the current entering and leaving should satisfy:

$$I_1 = I_2 + I_3.$$

Step 3: Apply Kirchhoff's Voltage Law (KVL) in loop ABFG: For loop ABFG, the sum of voltage drops equals the sum of emf sources:

$$3 - 2I_1 - 4I_2 - 6 = 0.$$

Simplify:

$$-2I_1 - 4I_2 = 3.$$
$$2I_1 + 4I_2 = 3. \tag{1}$$

Step 4: Apply KVL in loop BFCD: For loop BFCD:

$$-4I_2 + 6 - 2I_3 - 6 = 0.$$

Simplify:

$$-4I_2 - 2I_3 = 0.$$
$$2I_2 + I_3 = 0. \tag{2}$$

Step 5: Apply KVL in loop CDAB: For loop CDAB:

$$6 - 2I_3 - 2I_1 - 3 = 0.$$

Simplify:

$$-2I_3 - 2I_1 = -3.$$
$$I_3 + I_1 = \frac{3}{2}. \tag{3}$$

Step 6: Solve the equations: From equations (1), (2), and (3), solve for I_1, I_2, and I_3.

- From equation (2): $I_3 = -2I_2$.
- Substitute $I_3 = -2I_2$ into equation (3):

  $$-2I_2 + I_1 = \frac{3}{2}.$$

  Simplify:

  $$I_1 = 2I_2 + \frac{3}{2}. \tag{4}$$

- Substitute $I_1 = 2I_2 + \frac{3}{2}$ into equation (1):

$$2(2I_2 + \frac{3}{2}) + 4I_2 = 3.$$

Expand and simplify:

$$4I_2 + 3 + 4I_2 = 3.$$

$$8I_2 = 0 \implies I_2 = 0.$$

Step 7: Find I_1 and I_3:

- From equation (4): $I_1 = 2(0) + \frac{3}{2} = \frac{3}{2}\,\text{A}$.
- From equation (2): $I_3 = -2(0) = 0$.

Final Answer:

- Current in branch AG: $I_1 = \frac{3}{2}\,\text{A}$ (clockwise).
- Current in branch BF: $I_2 = 0\,\text{A}$ (no current flows).
- Current in branch CD: $I_3 = 0\,\text{A}$ (no current flows).

Quick Tip

To analyze circuits with multiple loops, always use KVL and KCL systematically. Assign directions to currents and verify the solution with consistent signs.

Question 23:
(a) On what factors does the speed of an electromagnetic wave in a medium depend?

(b)How is an electromagnetic wave produced?

(c)Sketch a schematic diagram depicting the electric and magnetic fields for an electromagnetic wave propagating along the z-axis.

Solution:

(a) Factors affecting the speed of an electromagnetic wave:
The speed of an electromagnetic wave (v) in a medium depends on the following factors:

- **Permittivity of the medium** (ϵ): Higher permittivity leads to slower wave propagation.
- **Permeability of the medium** (μ): Higher permeability reduces the speed of the wave.
- The relationship is given by:

$$v = \frac{1}{\sqrt{\mu\epsilon}}$$

where μ is the permeability and ϵ is the permittivity of the medium.

In a vacuum, the speed of light (c) is given as:

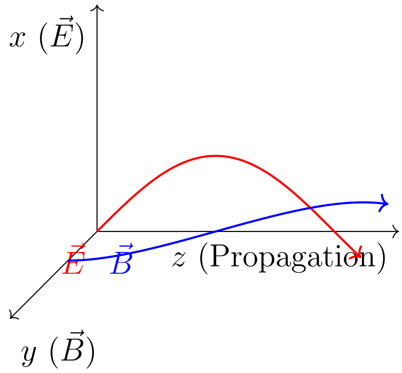
$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \quad \text{where} \quad c \approx 3 \times 10^8 \, \text{m/s}.$$

(b) Production of an electromagnetic wave:
Electromagnetic waves are produced by accelerated charges. When a charge undergoes acceleration (e.g., oscillating motion), it emits energy in the form of electromagnetic radiation. The oscillating electric field generates a time-varying magnetic field, and the time-varying magnetic field induces an electric field. This self-sustaining process results in the propagation of the electromagnetic wave.

(c) Diagram:
Below is a schematic diagram showing the electric field ($\vec{E}$) and magnetic field ($\vec{B}$) components of an electromagnetic wave propagating along the z-axis.

(Insert Diagram Here)

The electric field vector ($\vec{E}$) oscillates along the x-axis, the magnetic field vector ($\vec{B}$) oscillates along the y-axis, and the wave propagates along the z-axis. The three vectors $\vec{E}$, $\vec{B}$, and the direction of propagation ($\vec{k}$) are mutually perpendicular to each other.



Quick Tip

- $\vec{E}$, $\vec{B}$, and the direction of propagation are mutually perpendicular.
- The wave propagates along the z-axis.
- The electric field oscillates along the x-axis, and the magnetic field oscillates along the y-axis.

Question 24: A 100-turn coil of radius 1.6 cm and resistance 5.0 Ω is co-axial with a solenoid of 250 turns/cm and radius 1.8 cm. The solenoid current drops from 1.5 A to zero in 25 ms. Calculate the current induced in the coil in this duration. (Take $\pi^2 = 10$)

Solution:

Calculation of Current Induced in the Coil
Induced emf (ε):

$$\varepsilon = -N\frac{d\Phi}{dt}$$
$$= -NA\frac{dB}{dt}$$
$$= -NA\frac{d}{dt}(\mu_0 nI)$$
$$= -N\mu_0 n(\pi r^2)\frac{dI}{dt}$$

Substituting the values:

$$\varepsilon = \frac{100 \times 4\pi \times 10^{-7} \times 250 \times 10^2 \times \pi \times (1.6 \times 10^{-2})^2 \times 1.5}{25 \times 10^{-3}} = 0.1536\,\text{V}$$

The current I is:

$$I = \frac{\varepsilon}{R} = \frac{0.1536}{5} = 0.03\,\text{A}$$

Alternatively:

$$\varepsilon = -M\frac{dI}{dt}$$
$$M = \mu_0 nn'\pi r^2 l$$
$$M = \mu_0(n_1)(n_2)\pi r^2 l = 4\pi \times 10^{-7} \times 100 \times 250 \times 10^2 \times \pi \times (1.6 \times 10^{-2})^2 = 2.56 \times 10^{-3}\,\text{H}$$

Substituting this into the formula for emf:

$$\varepsilon = -2.56 \times 10^{-3} \times (0 - 1.5) \times 10^{-3} = 0.1536\,\text{V}$$

The current is:

$$I = \frac{\varepsilon}{R} = \frac{0.1536}{5} = 0.03\,\text{A}$$

Quick Tip

To calculate the induced current in the coil, use Faraday's law of electromagnetic induction:

$$\varepsilon = -N\frac{d\Phi}{dt}$$

Where: - ε is the induced emf, - N is the number of turns in the coil, - Φ is the magnetic flux, - $\frac{d\Phi}{dt}$ is the rate of change of magnetic flux.
Additionally, the induced current I is related to the emf and the resistance of the coil by Ohm's law:

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

Question 25(a): Two long, straight, parallel conductors carry steady currents in opposite directions. Explain the nature of the force of interaction between them. Obtain an expression for the magnitude of the force between the two conductors. Hence define one ampere.

Solution:
Nature of the force: The force between two parallel conductors carrying currents depends on the direction of the currents:

- If the currents flow in the **same direction**, the force is **attractive**.
- If the currents flow in **opposite directions**, the force is **repulsive**.

Expression for force:
Consider two conductors separated by a distance d, carrying currents I_1 and I_2. The magnetic field produced by conductor 1 at the location of conductor 2 is:

$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

The force on conductor 2 due to B_1 is:

$$F = I_2 l B_1 = I_2 l \frac{\mu_0 I_1}{2\pi d}$$

Thus, the force per unit length is:

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

Definition of one ampere:
One ampere is defined as the current that, when flowing through each of two long, straight, parallel conductors separated by a distance of 1 meter in a vacuum, produces a force of 2×10^{-7} N/m on each conductor.

Question 25(b): Obtain an expression for the torque $\vec{\tau}$ acting on a current-carrying loop in a uniform magnetic field $\vec{B}$. Draw the necessary diagram.

Solution:
Consider a rectangular loop of area A, carrying a current I, placed in a uniform magnetic field $\vec{B}$. The torque $\vec{\tau}$ acting on the loop is given by:

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

where $\vec{m}$ is the magnetic moment of the loop, given by:

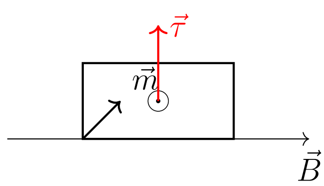
$$\vec{m} = I \cdot A\,\hat{n}$$

Here, $\hat{n}$ is the unit vector perpendicular to the plane of the loop.
The magnitude of the torque is:

$$\tau = mB\sin\theta = IAB\sin\theta$$

where θ is the angle between $\vec{m}$ and $\vec{B}$.

Diagram:



💡 Quick Tip

The torque $\vec{\tau}$ acting on a current-carrying loop in a uniform magnetic field $\vec{B}$ is given by the expression:

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

where: - $\vec{m}$ is the magnetic moment of the loop, and - $\vec{B}$ is the magnetic field.
The magnetic moment $\vec{m}$ is given by:

$$\vec{m} = IA\hat{n}$$

where: - I is the current in the loop, - A is the area of the loop, and - $\hat{n}$ is a unit vector perpendicular to the plane of the loop (directed according to the right-hand rule).
The magnitude of the torque is:

$$\tau = IAB\sin\theta$$

where θ is the angle between $\vec{m}$ and $\vec{B}$.

Question 26: Using Bohr's postulates, derive the expression for the radius of the nth orbit of an electron in a hydrogen atom. Also, find the numerical value of Bohr's radius a_0.

Solution:

Deriving Expression for Radius Finding Numerical Value of a_0
From Bohr's second postulate:

$$mvr = \frac{nh}{2\pi} \quad \ldots(1)$$

Also,

$$mv^2 = \frac{e^2}{4\pi\epsilon_0 r^2} \quad (z = 1)$$

The velocity v is:

$$v = \frac{e}{\sqrt{4\pi\epsilon_0 mr}}$$

Substituting in equation (1) and simplifying:

$$r = \frac{n^2h^2\epsilon_0}{\pi me^2}$$

For $n = 1$, the radius is $r = a_0$ (Bohr's radius):

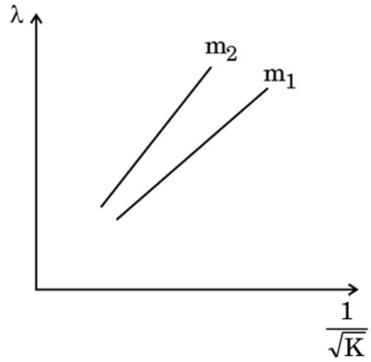
$$a_0 = \frac{(6.63 \times 10^{-34})^2 \times 8.854 \times 10^{-12}}{3.14 \times 9.1 \times 10^{-31} \times (1.6 \times 10^{-19})^2}$$

$$a_0 = 5.29 \times 10^{-11}\,\text{m} = 0.53\,\text{Å}$$

💡 Quick Tip

The radius of the nth orbit in a hydrogen atom increases as n^2. For the ground state ($n = 1$), the radius is equal to a_0, known as the Bohr radius.

Question 27: de Broglie wavelength λ as a function of $\frac{1}{\sqrt{K}}$, for two particles of masses m_1 and m_2 are shown in the figure below. Here, K is the energy of the moving particles.



(a)What does the slope of a line represent?
(b)Which of the two particles is heavier?
(c)Is this graph also valid for a photon? Justify your answer in each case.

Correct Answer:

1. The slope of the line represents $\frac{h}{\sqrt{2m}}$, where h is Planck's constant, and m is the mass of the particle.

2. Particle m_1 is heavier than m_2 because the slope of m_1 is smaller than that of m_2. A smaller slope corresponds to a larger mass.

3. No, this graph is not valid for a photon. For a photon, the de Broglie wavelength is given by $\lambda = \frac{h}{p}$, where p is the momentum. Since K for a photon is directly related to its energy ($E = pc$), the relationship would not produce the same $\frac{1}{\sqrt{K}}$ dependence.

Solution:
The de Broglie wavelength λ is related to the kinetic energy K of a particle as:

$$\lambda = \frac{h}{p}, \quad \text{where } p = \sqrt{2mK}.$$

Substituting p:

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

Rewriting:

$$\lambda \propto \frac{1}{\sqrt{K}} \quad \text{with slope } \frac{h}{\sqrt{2m}}.$$

(a): The slope $\frac{h}{\sqrt{2m}}$ represents the proportionality constant between λ and $\frac{1}{\sqrt{K}}$, which depends on the mass of the particle.

(b): Since $\frac{1}{\sqrt{2m}}$ is inversely proportional to mass m, the heavier particle (m_1) has a smaller slope compared to the lighter particle (m_2).

(c): For a photon, $K = pc$, where p is momentum and c is the speed of light. The relationship $\lambda = \frac{h}{p}$ does not depend on $\sqrt{K}$ but directly on p. Thus, this graph is not valid for a photon.

Quick Tip

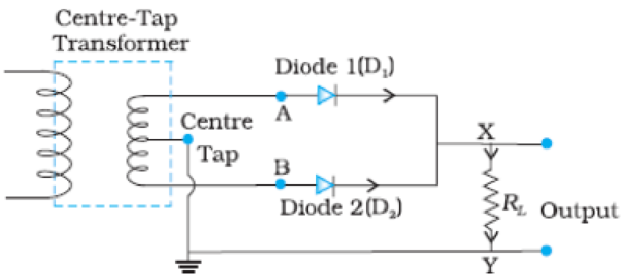
The slope of λ vs $\frac{1}{\sqrt{K}}$ is inversely proportional to the square root of the mass of the particle. Always check the context (e.g., whether for photons or massive particles) before applying the formula.

Question 28: With the help of a circuit diagram, explain the working of a p-n junction diode as a full wave rectifier. Draw its input and output waveforms.

Solution:

Introduction:
A full-wave rectifier converts the entire alternating current (AC) signal into direct current (DC). It uses two diodes in a center-tapped transformer configuration to achieve rectification.

Circuit Diagram:

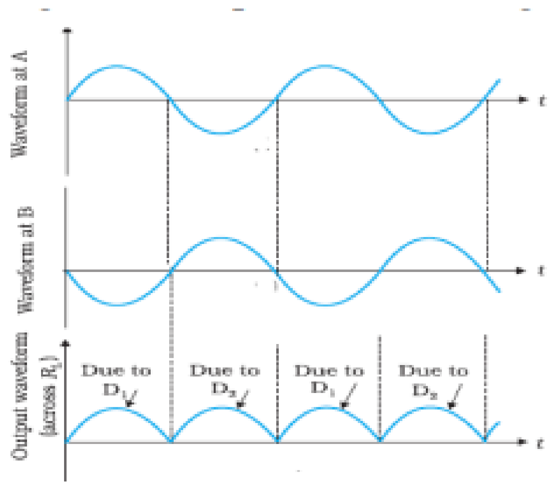


Working:

1. The circuit consists of:
   - A center-tapped transformer.
   - Two p-n junction diodes (D_1 and D_2).
   - A load resistor (R_L).
2. **Positive half-cycle of AC:**
   During the positive half-cycle of the input AC signal:
   - The upper end of the transformer is positive, and the lower end is negative.
   - Diode D_1 is forward biased and conducts current, while D_2 is reverse biased and does not conduct.
   - The current flows through D_1, the load resistor R_L, and back to the transformer.

3. **Negative half-cycle of AC:**
During the negative half-cycle of the input AC signal:
   - The upper end of the transformer is negative, and the lower end is positive.
   - Diode D_2 is forward biased and conducts current, while D_1 is reverse biased and does not conduct.
   - The current flows through D_2, the load resistor R_L, and back to the transformer.
4. **Output:**
In both half-cycles, the current through the load resistor flows in the same direction, resulting in a pulsating DC output.

Input and Output Waveforms:



Characteristics of the Output:
The output is a pulsating DC signal. A filter (e.g., a capacitor) can be used to smooth the output further.

> Quick Tip
>
> In a full-wave rectifier, both diodes work alternately during each half-cycle of the AC signal, ensuring continuous DC output. Always use a center-tapped transformer for this configuration.

SECTION D
Question 29: When the terminals of a cell are connected to a conductor of resistance R, an electric current flows through the circuit. The electrolyte of the cell also offers some resistance in the path of the current, like the conductor. This resistance offered by the electrolyte is called internal resistance of the cell (r). It depends upon the nature of the electrolyte, the area of the electrodes immersed in the electrolyte, and the temperature. Due to internal resistance, a part of the energy supplied by the cell is wasted in the form of heat. When no current is drawn from the cell, the potential difference between the two electrodes is known as the emf of the cell (ϵ). With a current drawn from the cell, the potential difference

between the two electrodes is termed as terminal potential difference (V).

(i) Choose the incorrect statement:

(A)The potential difference (V) between the two terminals of a cell in a closed circuit is always less than its emf (ϵ), during discharge of the cell.

(B) The internal resistance of a cell decreases with the decrease in temperature of the electrolyte.

(C) When current is drawn from the cell then $V = \epsilon - Ir$.

(D)The graph between potential difference between the two terminals of the cell (V) and the current (I) through it is a straight line with a negative slope.

Correct Answer: (B)

Solution:
Let us analyze each statement:

1. **True.** During discharge of the cell, the terminal potential difference V is given by $V = \epsilon - Ir$, which is always less than the emf ϵ when current flows.

2. **Incorrect.** The internal resistance of a cell *increases* with the decrease in temperature of the electrolyte. Lower temperature makes it harder for ions to move, thus increasing resistance.

3. **True.** The equation $V = \epsilon - Ir$ accurately represents the relationship between terminal potential difference, emf, current, and internal resistance of the cell.

4. **True.** The graph between V and I is given by the equation $V = \epsilon - Ir$, which is a straight line with a negative slope $-r$.

Thus, the incorrect statement is (B).

Quick Tip

Remember that internal resistance increases with a decrease in temperature and vice versa. The relationship $V = \epsilon - Ir$ is key to understanding the terminal potential difference in a circuit.

(ii) Two cells of emfs $2.0\,\mathrm{V}$ and $6.0\,\mathrm{V}$ and internal resistances $0.1\,\Omega$ and $0.4\,\Omega$ respectively, are connected in parallel. The equivalent emf of the combination will be:

(A) 2.0 V
(B) 2.8 V
(C) 6.0 V
(D) 8.0 V

Correct Answer: (B) 2.8 **V**

Solution:
When cells with emfs $\mathcal{E}_1$ and $\mathcal{E}_2$ and internal resistances r_1 and r_2 are connected in parallel, the equivalent emf $\mathcal{E}_{\text{eq}}$ is given by:

$$\mathcal{E}_{\text{eq}} = \frac{\mathcal{E}_1 r_2 + \mathcal{E}_2 r_1}{r_1 + r_2}.$$

Substitute the given values:

$$\mathcal{E}_1 = 2.0\,\text{V}, \quad \mathcal{E}_2 = 6.0\,\text{V}, \quad r_1 = 0.1\,\Omega, \quad r_2 = 0.4\,\Omega.$$

Calculate the numerator:

$$\mathcal{E}_1 r_2 = 2.0 \times 0.4 = 0.8\,\text{V},$$
$$\mathcal{E}_2 r_1 = 6.0 \times 0.1 = 0.6\,\text{V}.$$

Sum the terms in the numerator:

$$\mathcal{E}_1 r_2 + \mathcal{E}_2 r_1 = 0.8 + 0.6 = 1.4\,\text{V}.$$

Calculate the denominator:

$$r_1 + r_2 = 0.1 + 0.4 = 0.5\,\Omega.$$

Substitute these into the formula for $\mathcal{E}_{\text{eq}}$:

$$\mathcal{E}_{\text{eq}} = \frac{1.4}{0.5} = 2.8\,\text{V}.$$

Thus, the equivalent emf of the combination is:

$$\boxed{\mathcal{E}_{\text{eq}} = 2.8\,\text{V}}.$$

Quick Tip

For cells connected in parallel, the equivalent emf is a weighted average of the individual emfs, weighted by the internal resistances of the cells. Always use the formula:

$$\mathcal{E}_{\text{eq}} = \frac{\mathcal{E}_1 r_2 + \mathcal{E}_2 r_1}{r_1 + r_2}.$$

(iii) Dipped in the solution, the electrode exchanges charges with the electrolyte. The positive electrode develops a potential V_+ ($V_+ > 0$), and the negative electrode

develops a potential $-V_-$ ($V_- \geq 0$), relative to the electrolyte adjacent to it. When no current is drawn from the cell, the cell potential ε is:
(A) $\varepsilon = V_+ + V_- > 0$
(B) $\varepsilon = V_+ - V_- > 0$
(C) $\varepsilon = V_+ + V_- < 0$
(D) $\varepsilon = V_+ + V_- = 0$
Correct Answer: (A) $\varepsilon = V_+ + V_- > 0$
Solution:
When no current is drawn from the cell, the total potential difference across the cell is the sum of the potentials of the positive and negative electrodes relative to the electrolyte. The positive electrode develops a potential V_+ (greater than zero), and the negative electrode develops a potential $-V_-$ (with $V_- \geq 0$). Since these potentials are relative to the electrolyte, the net potential difference across the entire cell is:

$$\varepsilon = V_+ + V_-$$

Given that both V_+ and V_- are positive quantities, the total potential ε is greater than zero. Hence, the correct answer is **(A)**.

Quick Tip

In electrochemical cells, the cell potential is the sum of the potentials of the individual electrodes relative to the electrolyte. When no current is drawn, the net potential is always positive if both electrode potentials are positive.

(iv) (a) Five identical cells, each of emf 2 V and internal resistance 0.1 Ω, are connected in parallel. This combination is connected to an external resistor of 9.98 Ω. The current flowing through the resistor is:
(A) 0.05 A
(B) 0.1 A
(C) 0.15 A
(D) 0.2 A
Correct Answer: (D) 0.2 A

Solution: The emf of each cell is 2 V and the internal resistance of each cell is 0.1 Ω. Since the cells are connected in parallel, the equivalent emf of the combination remains the same as the emf of one cell (i.e., 2 V).

Next, the total internal resistance r_{eq} of the parallel combination of 5 cells, each with resistance 0.1 Ω, is given by:

$$\frac{1}{r_{\text{eq}}} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \frac{1}{r} = \frac{5}{r}$$

$$r_{\text{eq}} = \frac{r}{5} = \frac{0.1}{5} = 0.02\,\Omega$$

Now, the total resistance in the circuit is the sum of the equivalent internal resistance r_{eq} and the external resistor $R = 9.98\,\Omega$:

$$R_{total} = r_{eq} + R = 0.02 + 9.98 = 10\,\Omega$$

Using Ohm's law, the total current I_{total} supplied by the combination of cells is:

$$I_{total} = \frac{E_{total}}{R_{total}} = \frac{2}{10} = 0.2\,\text{A}$$

Thus, the current flowing through the external resistor is 0.2 A. Therefore, the correct answer is **(D)**.

Quick Tip

When cells are connected in parallel, the equivalent internal resistance is reduced. The total current supplied by the cells depends on both the emf of the cells and the total resistance (internal + external).

(iv) (b): The potential difference across a cell in the open circuit is $6\,\text{V}$. It becomes $4\,\text{V}$ when a current of $2\,\text{A}$ is drawn from it. The internal resistance of the cell is:
(A) $1.0\,\Omega$
(B) $1.5\,\Omega$
(C) $2.0\,\Omega$
(D) $2.5\,\Omega$

Correct Answer: (A) $1.0\,\Omega$

Solution:
The terminal potential difference is given by:

$$V = \epsilon - Ir,$$

where:

- $V = 4\,\text{V}$ (terminal voltage),
- $\epsilon = 6\,\text{V}$ (emf of the cell),
- $I = 2\,\text{A}$ (current),
- $r = ?$ (internal resistance).

Rearranging the equation for r:

$$r = \frac{\epsilon - V}{I}.$$

Substitute the values:

$$r = \frac{6-4}{2} = \frac{2}{2} = 1.0\,\Omega.$$

Thus, the internal resistance of the cell is:

$$\boxed{1.0\,\Omega}.$$

💡 Quick Tip

For internal resistance problems, use the relationship $r = \frac{\epsilon - V}{I}$, where ϵ is the emf, V is the terminal voltage, and I is the current.

Question 30: When a ray of light propagates from a denser medium to a rarer medium, it bends away from the normal. When the incident angle is increased, the refracted ray deviates more from the normal. For a particular angle of incidence in the denser medium, the refracted ray just grazes the interface of the two surfaces. This angle of incidence is called the critical angle for the pair of media involved.

(i) For a ray incident at the critical angle, the angle of reflection is:
(A) $0°$
(B) $< 90°$
(C) $> 90°$
(D) $90°$
Correct Answer: (D) $90°$

Solution: The critical angle occurs when the angle of refraction is $90°$, meaning the refracted ray travels along the boundary. At this point, the angle of incidence equals the critical angle. The angle of reflection is always equal to the angle of incidence, as per the law of reflection.

For a ray incident at the critical angle, the angle of reflection is thus $90°$. Therefore, the correct answer is **(D)**.

💡 Quick Tip

When a ray strikes at the critical angle, the angle of reflection is equal to the critical angle, and the refracted ray travels along the boundary between the two mediums.

(ii)A ray of light of wavelength 600 nm is incident in water (n= 4/3) on the water-air interface at an angle less than the critical angle. The wavelength associated with the refracted ray is :

(A) 400 nm
(B) 450 nm
(C) 600 nm
(D) 800 nm

Solution The wavelength of light in the rarer medium (air) is related to its wavelength in the denser medium (water) by the refractive index:

$$\lambda_{\text{air}} = \frac{\lambda_{\text{water}}}{n},$$

where:

- $\lambda_{\text{water}} = 600\,\text{nm}$,
- $n = \frac{4}{3}$ (refractive index of water with respect to air).

Substitute the values:

$$\lambda_{\text{air}} = 600 \times \frac{4}{3} = 800\,\text{nm}.$$

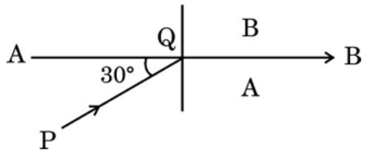
Thus, the wavelength of the refracted ray is:

$$\boxed{800\,\text{nm}}.$$

Quick Tip

Remember that at the critical angle, the refracted ray makes an angle of 90° with the normal. The wavelength in the rarer medium is larger than in the denser medium, and the relationship is inversely proportional to the refractive index.

(iii) (a): The interface AB between the two media A and B is shown in the figure. In the denser medium A, the incident ray PQ makes an angle of 30° with the horizontal. The refracted ray is parallel to the interface. The refractive index of medium B with respect to medium A is:



(A) $\frac{\sqrt{3}}{2}$
(B) $\frac{\sqrt{5}}{2}$
(C) $\frac{4}{\sqrt{3}}$
(D) $\frac{2}{\sqrt{3}}$

Correct Answer: (A) $\frac{\sqrt{3}}{2}$

Solution:
The incident ray makes an angle of 30° with the horizontal. Therefore, the angle of incidence with respect to the normal is:

$$i = 90^\circ - 30^\circ = 60^\circ.$$

Since the refracted ray is parallel to the interface, the angle of refraction r is:

$$r = 90^\circ.$$

Using Snell's law:

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

where:

- $n_1 = 1$ (refractive index of medium A with respect to itself),
- $\sin i = \sin 60^\circ = \frac{\sqrt{3}}{2}$,
- $\sin r = \sin 90^\circ = 1$.

Substitute the values:

$$n_1 \sin i = n_2 \sin r \implies 1 \cdot \frac{\sqrt{3}}{2} = n_2 \cdot 1.$$

Thus:

$$n_2 = \frac{\sqrt{3}}{2}.$$

The refractive index of medium B with respect to medium A is:

$$\boxed{\frac{\sqrt{3}}{2}}.$$

(b) Two media A and B are separated by a plane boundary. The speed of light in medium A and B is $2 \times 10^8\,\mathbf{ms^{-1}}$ and $2.5 \times 10^8\,\mathbf{ms^{-1}}$ respectively. The critical angle for a ray of light going from medium A to medium B is:
(A) $\sin^{-1}\frac{1}{2}$
(B) $\sin^{-1}\frac{4}{5}$
(C) $\sin^{-1}\frac{3}{5}$
(D) $\sin^{-1}\frac{2}{5}$
Correct Answer: (B) $\sin^{-1}\frac{4}{5}$
Solution: The critical angle θ_c is given by the relation:

$$\sin\theta_c = \frac{v_b}{v_a}$$

where: - v_a is the speed of light in medium A, - v_b is the speed of light in medium B.
Substituting the given values:

$$\sin\theta_c = \frac{2.5 \times 10^8}{2 \times 10^8} = \frac{5}{4}$$

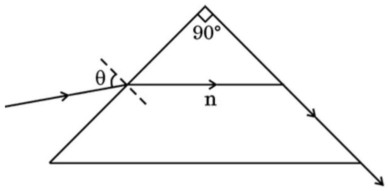
Thus,

$$\theta_c = \sin^{-1}\frac{4}{5}$$

Therefore, the correct answer is **(B)**.

> Quick Tip
>
> The critical angle is the angle of incidence above which total internal reflection occurs. It depends on the ratio of the speed of light in the two media and is given by $\sin\theta_c = \frac{v_b}{v_a}$.

(iv): The figure shows the path of a light ray through a triangular prism. In this phenomenon, the angle θ is given by:



(A) $\sin^{-1}\left(\sqrt{n^2-1}\right)$
(B) $\sin^{-1}\left(n^2-1\right)$
(C) $\sin^{-1}\left(\frac{1}{\sqrt{n^2-1}}\right)$
(E) $\sin^{-1}\left(\frac{1}{n^2-1}\right)$

Correct Answer: (A) $\sin^{-1}\left(\sqrt{n^2-1}\right)$

Solution:

The phenomenon involves the passage of light through a triangular prism where the ray undergoes total internal reflection at the base of the prism. The angle θ is determined using Snell's law and the geometry of the prism.

Step 1: Snell's Law at the first interface
At the first interface, Snell's law is applied:

$$n \sin\theta = 1 \sin 90^\circ = 1.$$

This gives:

$$\sin\theta = \frac{1}{n}.$$

Step 2: Relationship between θ and total internal reflection
For total internal reflection to occur at the base of the prism, the angle of incidence at the base must satisfy the critical angle condition:

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

From the geometry of the prism and using trigonometric relationships, the angle θ at the first interface is related to the refractive index n by:

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

Step 3: Final Expression for θ
Taking the inverse sine of both sides, the angle θ is given by:

$$\theta = \sin^{-1}\left(\sqrt{n^2-1}\right).$$

Thus, the correct answer is:

$$\boxed{\sin^{-1}\left(\sqrt{n^2-1}\right)}.$$

💡 Quick Tip

The relationship $\sin\theta = \sqrt{n^2-1}$ arises from the geometry and total internal reflection conditions in a prism. Always apply Snell's law and consider the refractive index carefully in such problems.

SECTION E
Question 31:

(i) Obtain an expression for the electric potential due to a small dipole of dipole moment $\vec{p}$, at a point $\vec{r}$ from its center, for much larger distances compared to the size of the dipole.

(ii) Three point charges q, $2q$, and nq are placed at the vertices of an equilateral triangle. If the potential energy of the system is zero, find the value of n.

Solutions:

a (i): Electric Potential of a Dipole:
The electric potential due to a dipole at a point $\vec{r}$ is given by:

$$V = \frac{1}{4\pi\epsilon_0}\frac{\vec{p}\cdot\hat{r}}{r^2},$$

where:

- $\vec{p}$ is the dipole moment,
- $\hat{r}$ is the unit vector along $\vec{r}$,
- r is the distance from the center of the dipole to the point of observation.

For large distances compared to the size of the dipole:

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

where θ is the angle between $\vec{p}$ and $\vec{r}$.

a (ii): Value of n:
The potential energy of the system is zero. The potential energy between two charges is given by:

$$U = \frac{1}{4\pi\epsilon_0}\sum_{i<j}\frac{q_i q_j}{r},$$

where r is the side of the equilateral triangle.
Substituting the charges q, $2q$, and nq, the total potential energy is:

$$U = \frac{1}{4\pi\epsilon_0 r}\left[q\cdot 2q + q\cdot nq + 2q\cdot nq\right].$$

Simplify:

$$U = \frac{1}{4\pi\epsilon_0 r}\left(2q^2 + nq^2 + 2nq^2\right).$$

Since $U = 0$:

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

Thus, the value of n is:

$$\boxed{-\frac{2}{3}}.$$

Question (b):
(i)State Gauss's Law in electrostatics. Apply this to obtain the electric field $\vec{E}$ at a point near a uniformly charged infinite plane sheet.

(ii) Two long straight wires 1 and 2 are kept as shown in the figure. The linear charge density of the two wires are $\lambda_1 = 10\,\mu$C/m and $\lambda_2 = -20\,\mu$C/m. Find the net force $\vec{F}$ experienced by an electron held at point P.

Solution:

b (i): Electric Field Near an Infinite Plane Sheet:
Gauss's Law: Gauss's Law states:

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enc}}}{\epsilon_0},$$

where:

- $\vec{E}$ is the electric field,
- $d\vec{A}$ is the infinitesimal area vector,
- Q_{enc} is the charge enclosed by the Gaussian surface,
- ϵ_0 is the permittivity of free space.

For a uniformly charged infinite plane sheet with surface charge density σ, consider a cylindrical Gaussian surface with its flat faces parallel to the sheet. The electric flux through the curved surface is zero, and the flux through the flat faces is:

$$\oint \vec{E} \cdot d\vec{A} = 2EA,$$

where A is the area of one flat face. Using Gauss's Law:

$$2EA = \frac{\sigma A}{\epsilon_0}.$$

Simplify:

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

Thus, the electric field near a uniformly charged infinite plane sheet is:

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

b (ii): Net Force on an Electron at Point P:

(ii)

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

According to the question,

$$E_1\,(\text{at point P}) = \frac{\lambda_1}{2\pi\epsilon_0 r_1}$$

$$\vec{E} = \frac{10 \times 10^{-6}}{2\pi\epsilon_0(10 \times 10^{-2})}\left(-\hat{j}\right)\ \text{N/C}$$

$$E_2\,(\text{at point P}) = \frac{\lambda_2}{2\pi\epsilon_0 r_2}$$

$$\vec{E} = \frac{20 \times 10^{-6}}{2\pi\epsilon_0(20 \times 10^{-2})}\left(-\hat{j}\right)\ \text{N/C}$$

The net electric field is:

$$E_{\text{net}} = \frac{10 \times 10^{-6}}{2\pi\epsilon_0}\left(\frac{1}{0.1} + \frac{2}{0.2}\right)\left(-\hat{j}\right)\ \text{N/C}$$

$$E_{\text{net}} = 3.6 \times 10^{6}\left(-\hat{j}\right)\ \text{N/C}$$

The force on the charge is:

$$\vec{F_{\text{net}}} = q \times \vec{E_{\text{net}}}$$

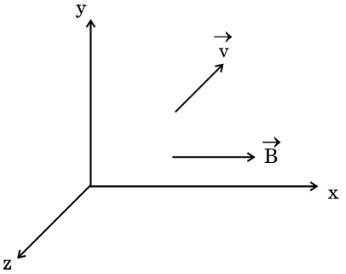
$$\vec{F} = -1.6 \times 10^{-19} \times 3.6 \times 10^{6}\left(-\hat{j}\right)\ \text{N}$$

$$\vec{F} = 5.76 \times 10^{-13}\left(\hat{j}\right)\ \text{N}$$

Quick Tip

For fields due to line charges, remember $E \propto \frac{\lambda}{r}$. Use vector addition for fields in perpendicular directions, and apply $F = eE$ for forces on charges in an electric field.

Question 32:
(i) A particle of mass m and charge q is moving with a velocity $\vec{v}$ in a magnetic field $\vec{B}$ as shown in the figure. Show that it follows a helical path. Hence, obtain its frequency of revolution.



(ii) In a hydrogen atom, the electron moves in an orbit of radius $2\,\text{Å}$ making 8×10^{14} revolutions per second. Find the magnetic moment associated with the orbital motion of the electron.

Solutions:

Part (a) (i): Helical Path of a Charged Particle in a Magnetic Field:
When a charged particle enters a magnetic field with velocity $\vec{v}$ at an angle to the field $\vec{B}$, the velocity $\vec{v}$ can be resolved into two components:

- $\vec{v}_{\parallel}$: The component parallel to $\vec{B}$.
- $\vec{v}_{\perp}$: The component perpendicular to $\vec{B}$.

Effect of $\vec{v}_{\parallel}$: The parallel component $\vec{v}_{\parallel}$ is unaffected by the magnetic field because the force due to the magnetic field is zero in this direction:

$$\vec{F} = q(\vec{v} \times \vec{B}) = 0\,(\text{if } \vec{v} \parallel \vec{B}).$$

Hence, the particle moves uniformly along the magnetic field in this direction.
Effect of $\vec{v}_{\perp}$: The perpendicular component $\vec{v}_{\perp}$ causes the particle to experience a magnetic force:

$$\vec{F} = q(\vec{v}_{\perp} \times \vec{B}),$$

which acts as a centripetal force, resulting in circular motion in the plane perpendicular to $\vec{B}$. The radius of the circular path is given by:

$$r = \frac{mv_{\perp}}{qB}.$$

Resulting Path: The combination of uniform motion along $\vec{B}$ and circular motion in the plane perpendicular to $\vec{B}$ results in a helical path.
Frequency of Revolution: The time period of revolution T is:

$$T = \frac{\text{Circumference of circle}}{\text{Speed in circular motion}} = \frac{2\pi r}{v_{\perp}}.$$

Substitute $r = \frac{mv_{\perp}}{qB}$:

$$T = \frac{2\pi\left(\frac{mv_{\perp}}{qB}\right)}{v_{\perp}} = \frac{2\pi m}{qB}.$$

The frequency of revolution f is:

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

Thus, the frequency of revolution is:

$$\boxed{f = \frac{qB}{2\pi m}}.$$

Part (a) (ii): Magnetic Moment of an Electron in Orbital Motion:
The magnetic moment μ associated with the orbital motion of a charged particle is given by:

$$\mu = I \cdot A,$$

where:

- I is the current,
- A is the area of the orbit.

Step 1: Calculate I (Current): The current is the charge passing through a point per unit time:

$$I = \frac{q}{T},$$

where q is the charge of the electron and T is the time period of revolution.
The time period is:

$$T = \frac{1}{f}.$$

Given:

$$f = 8 \times 10^{14} \text{ revolutions/second}, \quad q = 1.6 \times 10^{-19} \text{ C}.$$

Substitute:

$$I = q \cdot f = (1.6 \times 10^{-19})(8 \times 10^{14}) = 1.28 \times 10^{-4} \text{ A}.$$

Step 2: Calculate A (Area): The area of the circular orbit is:

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

where r is the radius of the orbit.
Given:

$$r = 2 \text{ Å} = 2 \times 10^{-10} \text{ m}.$$

Substitute:

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

Step 3: Calculate μ: Substitute I and A into $\mu = I \cdot A$:

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

Simplify:

$$\mu = 5.12\pi \times 10^{-24}.$$

Substitute $\pi \approx 3.14$:

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

Thus, the magnetic moment is:

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

Quick Tip

For helical motion, the magnetic force acts perpendicular to the velocity, resulting in circular motion in the plane perpendicular to the magnetic field. The parallel component of velocity ensures uniform motion along the field, forming a helix. For magnetic moments, remember $\mu = I \cdot A$.

Question (b):

(i) What is current sensitivity of a galvanometer? Show how the current sensitivity of a galvanometer may be increased. "Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity." Explain.

(ii) A moving coil galvanometer has a resistance of $15\,\Omega$ and takes $20\,\mathbf{mA}$ to produce full-scale deflection. How can this galvanometer be converted into a voltmeter of range 0 to $100\,\mathbf{V}$?

Solutions:

(i): Current Sensitivity of a Galvanometer:
The current sensitivity of a galvanometer is defined as the deflection produced per unit current. It is given by:

$$\text{Current Sensitivity} = \frac{\theta}{I},$$

where:

- θ is the deflection in the galvanometer,
- I is the current passing through the galvanometer.

The current sensitivity depends on:

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

where:

- n is the number of turns in the coil,
- B is the magnetic field,
- A is the area of the coil,
- k is the torsional constant of the suspension wire.

How to Increase Current Sensitivity: To increase the current sensitivity, we can:

- Increase the number of turns n,
- Increase the magnetic field B,
- Increase the area A of the coil,
- Decrease the torsional constant k of the suspension wire.

Why Increasing Current Sensitivity May Not Increase Voltage Sensitivity:
The voltage sensitivity of a galvanometer is defined as:

$$\text{Voltage Sensitivity} = \frac{\theta}{V} = \frac{\theta}{I \cdot R},$$

where R is the resistance of the galvanometer.
If the number of turns n is increased to enhance current sensitivity, it also increases the resistance R of the galvanometer. As a result, the voltage sensitivity may remain the same or even decrease because:

$$\text{Voltage Sensitivity} = \frac{\text{Current Sensitivity}}{R}.$$

Thus, increasing current sensitivity does not necessarily increase voltage sensitivity.

(ii): Conversion of Galvanometer into a Voltmeter:
To convert a galvanometer into a voltmeter of range 0 to 100 V, a high resistance R_s (series resistance) is connected in series with the galvanometer.
Step 1: Calculate Full-Scale Deflection Current (I_g):
The galvanometer takes 20 mA to produce full-scale deflection:

$$I_g = 20\,\text{mA} = 20 \times 10^{-3}\,\text{A}.$$

Step 2: Calculate the Required Series Resistance (R_s):
The total voltage across the galvanometer and the series resistance is given by Ohm's law:

$$V = I_g(R_g + R_s),$$

where:

- $V = 100\,\text{V}$ (voltmeter range),
- $R_g = 15\,\Omega$ (resistance of the galvanometer),
- $I_g = 20 \times 10^{-3}\,\text{A}$.

Rearranging for R_s:

$$R_s = \frac{V}{I_g} - R_g.$$

Substitute the values:

$$R_s = \frac{100}{20 \times 10^{-3}} - 15.$$

Simplify:

$$R_s = 5000 - 15 = 4985\,\Omega.$$

Thus, the series resistance required is:

$$\boxed{R_s = 4985\,\Omega}.$$

Step 3: Connection:
Connect a 4985 Ω resistance in series with the galvanometer to convert it into a voltmeter of range 0 to 100 V.

> Quick Tip
>
> To increase the range of a galvanometer, connect a high resistance in series. For voltmeter design, use the formula $R_s = \frac{V}{I_g} - R_g$ to calculate the required series resistance.

Question 33:

(a)(i)Give any two differences between the interference pattern obtained in Young's double-slit experiment and a diffraction pattern due to a single slit.

(a)(ii) Draw an intensity distribution graph in case of a double-slit interference pattern.

(a)(iii)In Young's double-slit experiment using monochromatic light of wavelength λ, the intensity of light at a point on the screen, where path difference is λ, is K units. Find the intensity of light at a point on the screen where the path difference is $\frac{\lambda}{6}$.

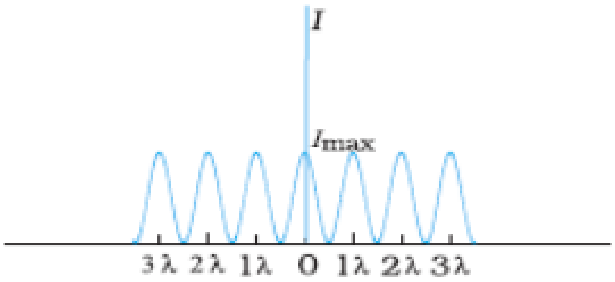
Solutions:

(a): Young's Double-Slit Experiment

(i) Differences Between Interference and Diffraction Patterns:

1. **Interference:** The interference pattern is formed due to the superposition of light waves from two coherent sources. The fringes are equally spaced and of uniform intensity.
2. **Diffraction:** The diffraction pattern is formed due to the bending of light around the edges of a single slit. The central maximum is brighter and wider, while the intensity of successive maxima decreases.

(ii) Intensity Distribution Graph: The intensity distribution in a double-slit interference pattern consists of bright and dark fringes. The intensity is maximum at the center and decreases symmetrically on either side. The graph looks like a sinusoidal wave.



(iii) Intensity at Path Difference $\frac{\lambda}{6}$: The intensity at any point is given by:

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

where ϕ is the phase difference.
The phase difference ϕ is related to the path difference Δx by:

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

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

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

Substitute $\phi = \frac{\pi}{3}$ into the intensity formula:

$$I = K \cos^2\left(\frac{\pi}{6}\right).$$

Using $\cos\frac{\pi}{6} = \frac{\sqrt{3}}{2}$:

$$I = K\left(\frac{\sqrt{3}}{2}\right)^2 = K \cdot \frac{3}{4}.$$

Thus, the intensity is:

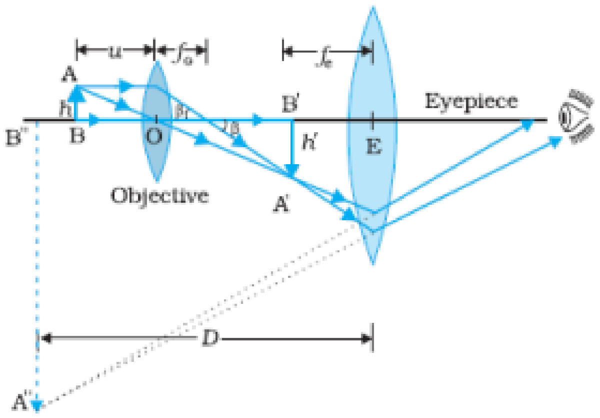
$$\boxed{\frac{3K}{4}}.$$

(b) (i)Draw a labelled ray diagram of a compound microscope showing image formation at least distance of distinct vision. Derive an expression for its magnifying power.

(ii) A telescope consists of two lenses of focal length 100 cm and 5 cm. Find the magnifying power when the final image is formed at infinity.

(b): Optical Instruments
(i) Compound Microscope:

Ray Diagram: The ray diagram for a compound microscope shows the formation of an enlarged image by the objective and eyepiece. The final image is virtual, erect, and formed at the least distance of distinct vision.



Magnifying Power: The magnifying power M of a compound microscope is given by:

$$M = m_o \cdot m_e,$$

where m_o is the magnification by the objective lens and m_e is the magnification by the eyepiece lens.
For the objective:

$$m_o = \frac{L}{f_o},$$

where L is the tube length and f_o is the focal length of the objective.
For the eyepiece:

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

where D is the least distance of distinct vision and f_e is the focal length of the eyepiece.
Combine:

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

(ii) Telescope:
The magnifying power M of a telescope for the final image formed at infinity is given by:

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

where f_o is the focal length of the objective and f_e is the focal length of the eyepiece.
Given:

$$f_o = 100\,\text{cm}, \quad f_e = 5\,\text{cm}.$$

Substitute:

$$M = \frac{100}{5} = 20.$$

Thus, the magnifying power is:

$$\boxed{20}.$$

Quick Tip

For interference patterns, use the intensity formula $I = I_0 \cos^2\left(\frac{\phi}{2}\right)$. For optical instruments, remember the standard formulas for magnifying power.
