CBSE Class 12 Physics 2024 Question Paper (55/5/1) With Solutions

Time Allowed :3 Hour	**Maximum Marks :**70	**Total questions :**33

General Instructions

Read the following instructions very carefully and strictly follow them:

1. This question paper contains 33 questions. All questions are compulsory.
2. This question paper is divided into five sections Sections A, B, C, D and E.
3. In Section A Questions no. 1 to 16 are Multiple Choice type questions. Each question carries 1 mark.
4. In Section B Questions no. 17 to 21 are Very Short Answer type questions.Each question carries 2 marks.
5. In Section C Questions no. 22 to 28 are Short Answer type questions. Each question carries 3 marks.
6. In Section D Questions no. 29 and 30 are case study based questions. Each question carries 4 marks.
7. In Section E Questions no. 31 to 33 are Long Answer type questions. Each question carries 5 marks.
8. 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. Kindly note that there is a separate question paper for Visually Impaired candidates.
10. Use of calculators is not allowed.

Section-A

1. A battery supplies 0.9 A current through a 2 Ω resistor and 0.3 A current through a 7 Ω resistor when connected one by one. The internal resistance of the battery is:

(A) 20 Ω

(B) 120 Ω

(C) 10 Ω

(D) 0.5 Ω

Correct Answer: (D) 0.5 Ω

Solution:

Let the internal resistance of the battery be r.

1. When the 2 Ω resistor is connected to the battery:

$$V = I_1 \cdot (R + r) = 0.9 \cdot (2 + r)$$

2. When the 7 Ω resistor is connected to the battery:

$$V = I_2 \cdot (R + r) = 0.3 \cdot (7 + r)$$

Since the battery voltage V is the same in both cases, we can equate both expressions:

$$0.9 \cdot (2 + r) = 0.3 \cdot (7 + r)$$

Expanding both sides:

$$1.8 + 0.9r = 2.1 + 0.3r$$

Simplifying:

$$0.9r - 0.3r = 2.1 - 1.8$$

$$0.6r = 0.3$$

$$r = \frac{0.3}{0.6} = 0.5\,\Omega$$

Thus, the internal resistance of the battery is $r = 0.5\,\Omega$.

Quick Tip

When resistors are connected to a battery, the current and voltage relations help to find the internal resistance using Ohm's law and the equality of battery voltage in both cases.

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2. A particle of mass m and charge q describes a circular path of radius R in a magnetic field. If its mass and charge were $2m$ and $\frac{q}{2}$ respectively, the radius of its path would be:

(A) $\frac{R}{4}$

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

(C) $2R$

(D) $4R$

Correct Answer: (D) $4R$

Solution:

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

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

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

For the given problem, the radius of the path is R for the particle with mass m and charge q. So, the radius of the path is:

$$R = \frac{mv}{qB} \quad (1)$$

Now, if the mass becomes $2m$ and the charge becomes $\frac{q}{2}$, the new radius r' will be:

$$r' = \frac{(2m)v}{\frac{q}{2}B} = \frac{2m \cdot v}{\frac{q}{2} \cdot B} = \frac{4mv}{qB}$$

Comparing this with equation (1), we get:

$$r' = 4R$$

Hence, the new radius of the path is $4R$.

Quick Tip

The radius of a charged particle's circular path in a magnetic field is proportional to its mass and inversely proportional to its charge. Doubling the mass and halving the charge increases the radius by a factor of 4.

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3. Which of the following pairs is that of paramagnetic materials?

(A) Copper and Aluminium

(B) Sodium and Calcium

(C) Lead and Iron

(D) Nickel and Cobalt

Correct Answer: (B) Sodium and Calcium

Solution:

Paramagnetic materials are materials that have unpaired electrons and are weakly attracted to a magnetic field. They do not retain magnetization in the absence of an external magnetic field.

Sodium and Calcium: Both sodium and calcium are paramagnetic materials. Sodium has unpaired electrons, and calcium also has unpaired electrons in its atomic structure, which makes both weakly attracted to a magnetic field.

Copper and Aluminium: Copper and aluminium are diamagnetic, not paramagnetic.

Lead and Iron: Lead is diamagnetic, and iron is ferromagnetic, so this pair does not represent paramagnetic materials.

Nickel and Cobalt: Both Nickel and Cobalt are ferromagnetic, not paramagnetic, because they have strong magnetic properties and retain magnetization.

Quick Tip

Paramagnetic materials are weakly attracted to a magnetic field due to the presence of unpaired electrons. Examples include Nickel and Cobalt.

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4. A galvanometer of resistance 50 Ω is converted into a voltmeter of range (0 — 2V) using a resistor of 1.0 kΩ. If it is to be converted into a voltmeter of range (0 — 10 V), the resistance required will be:

(A) 4.8k Ω

(B) 5.0k Ω

(C) 5.2k Ω

(D) 5.4k Ω

Correct Answer: (C) 5.2 kΩ

Solution:

Given:

- $R_g = 50$
- $R_s = 1.0 = 1000$
- $V_1 = 2$
- $V_2 = 10$

Current through the galvanometer:

$$I = \frac{V_1}{R_g + R_s} = \frac{2}{1050}$$

Total resistance for 10 range:

$$R_{\text{total}} = \frac{V_2}{I} = \frac{10}{\frac{2}{1050}} = 5250$$

Additional resistance required:

$$R_{\text{new}} = R_{\text{total}} - R_g = 5250 - 50 = 5.2$$

Answer: $\boxed{\text{(C) } 5.2}$

Quick Tip

To convert a galvanometer into a voltmeter, the total resistance required for the desired voltage range is calculated by using the current corresponding to the given voltage ranges. The series resistance is added to the galvanometer resistance.

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5. Two coils are placed near each other. When the current in one coil is changed at the rate of 5 A/s, an emf of 2 mV is induced in the other. The mutual inductance of the two coils is:

(A) 0.4 mH

(B) 25 mH

(C) 10 mH

(D) 25 H

Correct Answer: (A) 0.4 mH

Solution:

The induced emf $\mathcal{E}$ in a coil due to a changing current in a nearby coil is related to the mutual inductance M by the formula:

$$\mathcal{E} = M\frac{dI}{dt}$$

where: - $\mathcal{E} = 2\,\text{mV} = 2 \times 10^{-3}\,\text{V}$ is the induced emf, - $\frac{dI}{dt} = 5\,\text{A/s}$ is the rate of change of current.

Rearranging to solve for M:

$$M = \frac{\mathcal{E}}{\frac{dI}{dt}} = \frac{2 \times 10^{-3}\,\text{V}}{5\,\text{A/s}} = 4 \times 10^{-4}\,\text{H} = 0.4\,\text{mH}$$

Thus, the mutual inductance of the two coils is $M = 0.4\,\text{mH}$.

Quick Tip

The mutual inductance is calculated using the formula $\mathcal{E} = M\frac{dI}{dt}$, where the induced emf is proportional to the rate of change of current.

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6. The electromagnetic waves used to purify water are:

(A) Infrared rays

(B) Ultraviolet rays

(C) X-rays

(D) Gamma rays

Correct Answer: (B) Ultraviolet rays

Solution:

Ultraviolet (UV) rays are used to purify water because they have germicidal properties. UV rays can kill or deactivate harmful microorganisms by damaging their DNA, which makes them an effective method for water purification.

Infrared rays are primarily used for heating purposes.

X-rays and Gamma rays are used for medical imaging and cancer treatment but are not commonly used for water purification.

Thus, the correct answer is Ultraviolet rays.

> Quick Tip
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> Ultraviolet rays are effective in sterilizing and purifying water because they destroy the DNA of microorganisms, preventing them from reproducing.

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7. The focal lengths of the objective and the eyepiece of a compound microscope are 1 cm and 2 cm respectively. If the tube length of the microscope is 10 cm, the magnification obtained by the microscope for most suitable viewing by relaxed eye is:

(A) 250

(B) 200

(C) 150

(D) 125

Correct Answer: (D) 125

Solution:

The magnification M of a compound microscope is given by the formula:

$$M = \frac{D}{F_o} \times \frac{L}{F_e}$$

where: - D is the least distance of distinct vision (usually taken as 25 cm), - F_o is the focal length of the objective lens, - L is the tube length of the microscope, - F_e is the focal length of the eyepiece.

Given: - $D = 25\,\text{cm}$, - $F_o = 1\,\text{cm}$, - $F_e = 2\,\text{cm}$, - $L = 10\,\text{cm}$.

Substituting these values into the formula:

$$M = \frac{25}{1} \times \frac{10}{2} = 25 \times 5 = 125$$

Thus, the magnification obtained by the microscope is 125.

Quick Tip

The total magnification of a compound microscope is the product of the magnification due to the objective and the eyepiece. For relaxed eye viewing, the formula $M = \frac{D}{F_o} \times \frac{L}{F_e}$ gives the magnification.

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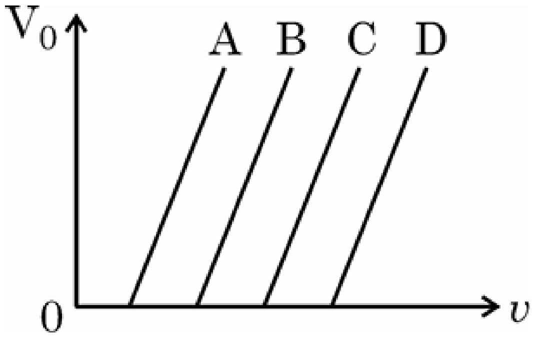
8. The variation of the stopping potential V_0 with the frequency ν of the incident radiation for four metals A, B, C, and D is shown in the figure. For the same frequency of incident radiation producing photo-electrons in all metals, the kinetic energy of photo-electrons will be maximum for which metal?



(A) A

(B) B

(C) C

(D) D

Correct Answer: (A) A

Solution: The stopping potential V_0 is directly related to the kinetic energy of the photoelectrons. The stopping potential increases with the frequency of the incident radiation, and the maximum kinetic energy of the photoelectrons will occur for the metal with the largest stopping potential for a given frequency. In the graph, the stopping potential V_0 is highest for metal A at a given frequency, indicating that the kinetic energy of the photoelectrons is maximum for metal A.

Quick Tip

The kinetic energy of photoelectrons is related to the stopping potential: $K.E. = eV_0$, where e is the charge of an electron. The metal with the highest stopping potential at a given frequency will have the maximum kinetic energy of photoelectrons.

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9. The energy of an electron in the ground state of hydrogen atom is -13.6 eV. The kinetic and potential energy of the electron in the first excited state will be:

(A) $-13.6\,\text{eV}, 27.2\,\text{eV}$

(B) $-6.8\,\text{eV}, 13.6\,\text{eV}$

(C) $3.4\,\text{eV}, -6.8\,\text{eV}$

(D) $6.8\,\text{eV}, -3.4\,\text{eV}$

Correct Answer: (C) 3.4 eV, -6.8 eV

Solution:

The energy of an electron in the hydrogen atom is given by the formula:

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

Where n is the principal quantum number. In the ground state, $n = 1$, so the energy of the electron in the ground state is:

$$E_1 = -\frac{13.6}{1^2} = -13.6\,\text{eV}$$

For the first excited state, $n = 2$, so the energy of the electron in the first excited state is:

$$E_2 = -\frac{13.6}{2^2} = -\frac{13.6}{4} = -3.4\,\text{eV}$$

Now, the total energy E_2 consists of both kinetic energy K and potential energy U. According to the Virial Theorem:

$$K = -\frac{1}{2}U$$

The total energy is:

$$E_2 = K + U$$

Since $K = -\frac{1}{2}U$, it follows that $E_2 = -\frac{1}{2}U + U = \frac{1}{2}U$, so $U = 2E_2$.

For the first excited state, we already know that $E_2 = -3.4\,\text{eV}$. Therefore:

$$U = 2 \times (-3.4) = -6.8\,\text{eV}$$

And since $K = -\frac{1}{2}U$:

$$K = -\frac{1}{2} \times (-6.8) = 3.4\,\text{eV}$$

Thus, the kinetic energy is $3.4\,\text{eV}$ and the potential energy is $-6.8\,\text{eV}$.

Correct Answer: (C) 3.4 eV, -6.8 eV

Quick Tip

In the Bohr model of the hydrogen atom, the total energy is the sum of the kinetic and potential energies. The kinetic energy is equal in magnitude but opposite in sign to the potential energy.

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10. A Young's double-slit experimental setup is kept in a medium of refractive index $\frac{4}{3}$. Which maximum in this case will coincide with the 6th maximum obtained if the medium is replaced by air?

(A) 4th

(B) 6th

(C) 8th

(D) 10th

Correct Answer: (C) 8th

Solution:

In Young's double-slit experiment, the condition for constructive interference (maxima) is given by:

$$d \sin\theta = m\lambda$$

where: - d is the distance between the slits, - θ is the angle of the maxima, - m is the order of the maxima, - λ is the wavelength of the light.

When the experiment is conducted in a medium with refractive index n, the wavelength of light in the medium changes. The new wavelength λ' in the medium is given by:

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

Now, in the case of the medium having refractive index $n = \frac{4}{3}$, the wavelength λ' is reduced compared to the wavelength in air. The maxima in the medium will shift because the wavelength has changed.

For the maximum in the medium to coincide with the 6th maximum in air, we need to adjust the order of maxima, taking into account the refractive index. Since the wavelength in the medium is smaller, the maxima will be shifted toward lower orders.

Thus, the maximum in the medium corresponding to the 6th maximum in air will be the 8th maximum in the medium.

Quick Tip

In interference experiments, the fringe separation Δy is given by:

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

where λ is the wavelength, D is the distance to the screen, and d is the distance between the slits. The fringe separation decreases as the refractive index increases.

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11. The potential energy between two nucleons inside a nucleus is minimum at a distance of about:

(A) 0.8 fm

(B) 1.6 fm

(C) 2.0 fm

(D) 2.8 fm

Correct Answer: (A) 0.8 fm

Solution:

The potential energy between two nucleons inside a nucleus is typically described by the nuclear potential, which consists of both attractive and repulsive components. The attractive force dominates at larger distances, while the repulsive force comes into play at very short distances due to the Pauli exclusion principle and other quantum mechanical effects.
The minimum potential energy occurs when the attractive and repulsive forces balance each other. This typically happens when the separation between nucleons is around **0.8 femtometers (fm)**, which is the typical distance at which nuclear forces are most effective.

Quick Tip

The minimum potential energy between nucleons in a nucleus corresponds to the equilibrium separation where the nuclear force is most effective at holding the nucleons together.

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12. A pure Si crystal having 5×10^{28} atoms m^{-3} is doped with 1 ppm concentration of antimony. If the concentration of holes in the doped crystal is found to be 4.5×10^{9} m^{-3}, the concentration (in m^{-3}) of intrinsic charge carriers in the Si crystal is about:

(A) 1.2×10^{15}

(B) 1.5×10^{6}

(C) 3.0×10^{15}

(D) 2.0×10^{6}

Correct Answer: (B) 1.5×10^{16}

Solution:

We are given the following information: - The concentration of silicon atoms in pure Si is 5×10^{28} m^{-3}. - The doping concentration of antimony is 1 ppm, which means $1\,\text{ppm} = \frac{1}{10^6}$. - The concentration of antimony in the doped Si is therefore:

$$\text{Concentration of Sb} = \frac{1}{10^6} \times 5 \times 10^{28} = 5 \times 10^{22}\,\text{m}^{-3}$$

- The concentration of holes in the doped crystal is 4.5×10^{9} m^{-3}.

Now, the intrinsic carrier concentration n_i in a semiconductor is given by the product of electron and hole concentrations:

$$n_i = \sqrt{n_e \times n_h}$$

where: - n_e is the concentration of electrons, - n_h is the concentration of holes.

In the doped Si crystal, the number of electrons is approximately equal to the concentration of the dopant atoms (antimony), i.e., $n_e \approx 5 \times 10^{22}\,\mathrm{m}^{-3}$. The concentration of holes n_h is $4.5 \times 10^{9}\,\mathrm{m}^{-3}$.

Thus, the intrinsic concentration of charge carriers n_i is:

$$n_i = \sqrt{5 \times 10^{22} \times 4.5 \times 10^{9}}$$

$$n_i = \sqrt{2.25 \times 10^{32}} = 1.5 \times 10^{16}\,\mathrm{m}^{-3}$$

Therefore, the concentration of intrinsic charge carriers is approximately $1.5 \times 10^{16}\,\mathrm{m}^{-3}$.

Quick Tip

The intrinsic carrier concentration n_i in semiconductors is important for understanding charge transport. In doped semiconductors, the carrier concentration is influenced by both the intrinsic carriers and the dopants.

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

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

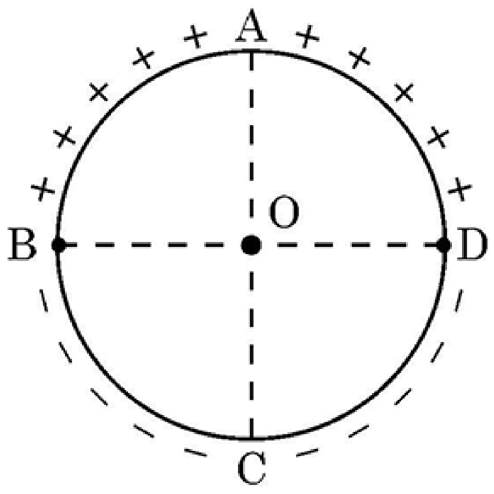
(B) If both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A).

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

(D) If both Assertion (A) and Reason (R) are false.

13. Assertion (A): Equal amount of positive and negative charges are distributed uniformly on two halves of a thin circular ring as shown in figure. The resultant electric field at the centre O of the ring is along OC.

Reason (R): It is so because the net potential at O is not zero.



Correct Answer: C If Assertion (A) is true but Reason (R) is false.

Solution: In this case, the charges are symmetrically placed on the two halves of the ring, and their electric fields at the center will cancel out in the directions perpendicular to the line joining the charges. Thus, the resultant electric field at O is along the axis OC, as the symmetry of the charge distribution ensures a non-zero field in this direction.

However, the net potential at O is indeed zero. This is because the potential due to positive charges and negative charges at the center of the ring cancels out symmetrically, leaving the potential at O to be zero. Therefore, the reason given in (R) is incorrect.

Thus, the assertion (A) is true, but the reason (R) is false.

Quick Tip

In electrostatics, the electric field due to symmetrically placed charges is directed along the symmetry axis. The potential, however, is scalar and adds algebraically, so for a system with symmetrical charge distribution, the net potential can be zero even when the electric field is not.

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14. Assertion (A): The energy of a charged particle moving in a magnetic field does not change.

Reason (R): It is because the work done by the magnetic force on the charge moving in a magnetic field is zero.

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

Solution: The energy of a charged particle remains constant while moving in a magnetic field because the magnetic force does no work on the particle. This is due to the fact that the magnetic force is always perpendicular to the velocity of the charged particle, and hence it does not change the kinetic energy.

Since the magnetic force does no work on the charged particle, the energy remains unchanged. Thus, both the assertion and the reason are true, and the reason correctly explains the assertion.

Quick Tip

The magnetic force on a charged particle is always perpendicular to its velocity, causing no change in kinetic energy.

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15. Assertion (A): In a Young's double-slit experiment, interference pattern is not observed when two coherent sources are infinitely close to each other.

Reason (R): The fringe width is proportional to the separation between the two sources.

Correct Answer: (C) If Assertion (A) is true but Reason (R) is false.

Solution:

Step 1:

In a Young's double-slit experiment, the interference pattern will not form clearly if the two coherent sources are infinitely close to each other. This is because the phase difference between the two sources becomes indeterminate, leading to no stable interference pattern.

Step 2:

The reason (R) is incorrect because the fringe width is actually inversely proportional to the separation between the slits, not directly proportional. As the separation between the slits increases, the fringe width decreases.

Quick Tip

For clear interference patterns in Young's experiment, the slits should be separated by a finite distance, and the sources should remain coherent.

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16. Assertion (A): An alpha particle is moving towards a gold nucleus. The impact parameter is maximum for the scattering angle of 180°.

Reason (R): The impact parameter in an alpha particle scattering experiment does not depend upon the atomic number of the target nucleus.

Correct Answer: (D) If both Assertion (A) and Reason (R) are false.

Solution: Analysis of Assertion (A):

The impact parameter (b) is the perpendicular distance between the path of the alpha particle and the center of the gold nucleus if no force acted on the alpha particle. The relationship between the impact parameter (b) and the scattering angle (θ) in Rutherford scattering is given by:

$$b \propto \cot\left(\frac{\theta}{2}\right)$$

For $\theta = 180$:

$$\cot\left(\frac{180}{2}\right) = \cot(90) = 0$$

This means the impact parameter (b) is **minimum** (close to zero) for a scattering angle of 180. Therefore, **Assertion (A) is false**.

Analysis of Reason (R):

The impact parameter (b) depends on the atomic number (Z) of the target nucleus. The relationship is given by:

$$b \propto \frac{1}{Z}$$

This means the impact parameter decreases as the atomic number of the target nucleus increases. Therefore, **Reason (R) is false**.

Conclusion:

- Assertion (A) is false.
- Reason (R) is false.

Thus, the correct answer is:

$$\boxed{\text{Both Assertion (A) and Reason (R) are false.}}$$

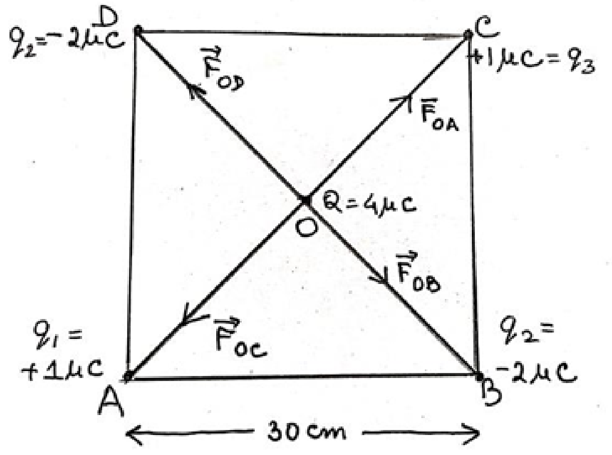
Quick Tip

In Rutherford scattering, the maximum scattering angle of 180° corresponds to the largest impact parameter, which occurs when the alpha particle is deflected directly back.

Section-B

17. (a) Four point charges of 1 μC, -2 μC, 1 μC, and -2 μC are placed at the corners A, B, C, and D respectively, of a square of side 30 cm. Find the net force acting on a charge of 4 μC placed at the center of the square.

Solution:



Given:

- Charges at the corners:
  - $q_A = 1\,\mu\text{C}$
  - $q_B = -2\,\mu\text{C}$
  - $q_C = 1\,\mu\text{C}$
  - $q_D = -2\,\mu\text{C}$
- Side of the square, $a = 30\,\text{cm} = 0.3\,\text{m}$
- Charge at the center, $q_0 = 4\,\mu\text{C}$

Step 1: Calculate the distance from the center to a corner. The distance (r) from the center of the square to any corner is half the length of the diagonal of the square. The diagonal (d) of the square is:

$$d = a\sqrt{2} = 0.3 \times \sqrt{2}\,\text{m}$$

Thus, the distance from the center to a corner is:

$$r = \frac{d}{2} = \frac{0.3 \times \sqrt{2}}{2} = 0.15 \times \sqrt{2}\,\text{m}$$

Step 2: Calculate the force due to each charge.

The force (F) between two charges is given by Coulomb's law:

$$F = \frac{k \cdot |q_1 \cdot q_2|}{r^2}$$

where $k = 9 \times 10^9\,\text{N m}^2/\text{C}^2$.

Forces due to charges at corners A, B, C, and D:

1. **Force due to q_A**:

$$F_A = \frac{9 \times 10^9 \cdot |1 \times 10^{-6} \cdot 4 \times 10^{-6}|}{(0.15 \times \sqrt{2})^2}$$

$$F_A = \frac{36 \times 10^{-3}}{0.045} = 0.8\,\text{N}$$

The direction of F_A is along the line from A to the center.

2. **Force due to q_B**:

$$F_B = \frac{9 \times 10^9 \cdot |-2 \times 10^{-6} \cdot 4 \times 10^{-6}|}{(0.15 \times \sqrt{2})^2}$$

$$F_B = \frac{72 \times 10^{-3}}{0.045} = 1.6\,\text{N}$$

The direction of F_B is along the line from B to the center.

3. **Force due to q_C**:

$$F_C = \frac{9 \times 10^9 \cdot |1 \times 10^{-6} \cdot 4 \times 10^{-6}|}{(0.15 \times \sqrt{2})^2}$$

$$F_C = \frac{36 \times 10^{-3}}{0.045} = 0.8\,\text{N}$$

The direction of F_C is along the line from C to the center.

4. **Force due to q_D**:

$$F_D = \frac{9 \times 10^9 \cdot |-2 \times 10^{-6} \cdot 4 \times 10^{-6}|}{(0.15 \times \sqrt{2})^2}$$

$$F_D = \frac{72 \times 10^{-3}}{0.045} = 1.6\,\text{N}$$

The direction of F_D is along the line from D to the center.

Step 3: Resolve forces into components.

The forces F_A and F_C are along the diagonals of the square, and F_B and F_D are along the other diagonals. Due to symmetry, the horizontal and vertical components of the forces cancel out.

Step 4: Calculate the net force.

Since the forces are symmetrically distributed and their components cancel out, the **net force on the charge at the center is zero**.

Final Answer:

$$\boxed{\text{The net force acting on the charge at the center is } 0\,\text{N.}}$$

Quick Tip

Remember to apply Coulomb's law for each charge, and use vector addition to determine the resultant force. The forces should be broken down into their components for easier addition.

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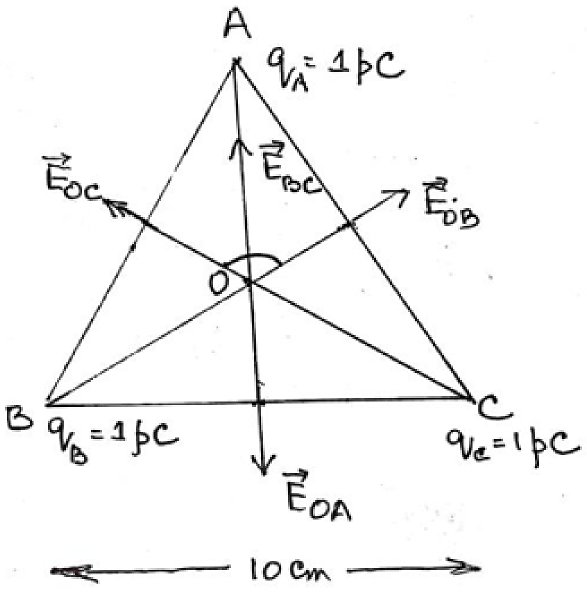
17. (b) Three point charges, 1 pC each, are kept at the vertices of an equilateral triangle of side 10 cm. Find the net electric field at the centroid of the triangle.

Solution:



Given:

- Charges at the vertices: $q_1 = q_2 = q_3 = 1\,\text{pC} = 1 \times 10^{-12}\,\text{C}$
- Side of the equilateral triangle: $a = 10\,\text{cm} = 0.1\,\text{m}$

Step 1: Calculate the distance from the centroid to a vertex.

For an equilateral triangle, the distance (r) from the centroid to any vertex is:

$$r = \frac{a}{\sqrt{3}} = \frac{0.1}{\sqrt{3}}\,\text{m}$$

Step 2: Calculate the electric field due to each charge.

The electric field (E) due to a point charge is given by:

$$E = \frac{k \cdot q}{r^2}$$

where $k = 9 \times 10^9\,\text{N m}^2/\text{C}^2$.

Electric fields due to charges at vertices:

1. **Electric field due to q_1**:

$$E_1 = \frac{9 \times 10^9 \cdot 1 \times 10^{-12}}{\left(\frac{0.1}{\sqrt{3}}\right)^2}$$

$$E_1 = 2.7\,\text{N/C}$$

The direction of E_1 is along the line from the centroid to q_1.

2. **Electric field due to q_2**:

$$E_2 = 2.7\,\text{N/C}$$

The direction of E_2 is along the line from the centroid to q_2.

3. **Electric field due to q_3**:

$$E_3 = 2.7\,\text{N/C}$$

The direction of E_3 is along the line from the centroid to q_3.

Step 3: Resolve the electric fields into components.

Due to the symmetry of the equilateral triangle, the electric fields E_1, E_2, and E_3 are at $120°$ to each other. The horizontal and vertical components of these fields will cancel out.

Step 4: Calculate the net electric field.

Since the electric fields are symmetrically distributed and their components cancel out, the **net electric field at the centroid is zero**.

Final Answer:

$$\boxed{\text{The net electric field at the centroid is } 0\,\text{N/C.}}$$

Quick Tip

For symmetrically placed charges in an equilateral triangle, the resultant electric field at the centroid can be found by calculating the field due to one charge and using the symmetry to sum the components.

18. Derive an expression for magnetic force $\vec{F}$ acting on a straight conductor of length L carrying current I in an external magnetic field $\vec{B}$. Is it valid when the conductor is in zig-zag form? Justify.

Solution: Step 1: The magnetic force $\vec{F}$ on a current-carrying conductor of length L is given by the formula:

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

where: - I is the current in the conductor, - L is the length of the conductor, - $\vec{B}$ is the external magnetic field, - $\hat{l}$ is the unit vector in the direction of the current.

Step 2: The force is calculated by the cross-product of the magnetic field and the direction of current. The magnitude of the force is:

$$F = ILB\sin\theta$$

where θ is the angle between the magnetic field $\vec{B}$ and the conductor.

Step 3: The direction of the force is given by the right-hand rule, which states that if the right-hand thumb is pointed in the direction of the current, and the fingers are pointed in the direction of the magnetic field, the palm faces in the direction of the force.

Step 4: When the conductor is in zig-zag form, the expression still holds, but the total length of the conductor will change. The force calculation will need to account for the effective length and the direction of current in each segment of the conductor. In the zig-zag case, the segments' contribution to the force will depend on the angle between each segment's direction of current and the magnetic field. Thus, while the general formula applies, the overall force will depend on the geometry of the zig-zag shape.

Quick Tip

The magnetic force on a current-carrying conductor depends on the angle between the magnetic field and the direction of current. The formula remains applicable even for zig-zag conductors, but the geometry must be considered for accurate calculation.

---

19. A telescope has an objective lens of focal length 150 cm and an eyepiece of focal length 5 cm. Calculate its magnifying power in normal adjustment and the distance of the image formed by the objective.

Solution: Step 1: The magnifying power M of the telescope in normal adjustment is given by the formula:

$$M = \frac{f_{\text{objective}}}{f_{\text{eyepiece}}}$$

where $f_{\text{objective}}$ is the focal length of the objective lens and f_{eyepiece} is the focal length of the eyepiece.

Step 2: Substituting the given values:

$$M = \frac{150\,\text{cm}}{5\,\text{cm}} = 30$$

Thus, the magnifying power of the telescope in normal adjustment is 30.

Step 3: To find the distance of the image formed by the objective, we use the lens formula:

$$\frac{1}{f_{\text{objective}}} = \frac{1}{v_{\text{objective}}} - \frac{1}{u_{\text{objective}}}$$

where $f_{\text{objective}}$ is the focal length of the objective lens, $v_{\text{objective}}$ is the image distance, and $u_{\text{objective}}$ is the object distance.

Step 4: In normal adjustment, the object is at infinity, so $u_{\text{objective}} \to \infty$. Therefore, the lens formula simplifies to:

$$\frac{1}{f_{\text{objective}}} = \frac{1}{v_{\text{objective}}}$$

$$v_{\text{objective}} = f_{\text{objective}} = 150\,\text{cm}$$

Thus, the distance of the image formed by the objective is 150 cm.

> Quick Tip
>
> The magnifying power of a telescope in normal adjustment is simply the ratio of the focal lengths of the objective and eyepiece. For an object at infinity, the image formed by the objective is at its focal point.

---

20. (a) Two energy levels of an electron in a hydrogen atom are separated by 2.55 eV. Find the wavelength of radiation emitted when the electron makes a transition from the higher energy level to the lower energy level.

Solution: The energy of a photon emitted during a transition between two energy levels is given by the equation:

$$E = h\nu$$

where:

E is the energy of the emitted radiation (in this case, $E = 2.55\,\text{eV}$),

$h = 6.626 \times 10^{-34}\,\text{J} \cdot \text{s}$ is Planck's constant,

ν is the frequency of the emitted radiation.

The frequency ν is related to the wavelength λ by the equation:

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

where:

$c = 3.0 \times 10^8$ m/s is the speed of light,

λ is the wavelength of the emitted radiation.

Substitute ν into the energy equation:

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

Rearranging for λ:

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

Now, substitute the given values:

$h = 6.626 \times 10^{-34}\,\mathrm{J \cdot s}$,

$c = 3.0 \times 10^8$ m/s,

$E = 2.55\,\mathrm{eV} = 2.55 \times 1.602 \times 10^{-19}\,\mathrm{J}$.

Thus:

$$\lambda = \frac{6.626 \times 10^{-34} \times 3.0 \times 10^8}{2.55 \times 1.602 \times 10^{-19}}$$

$$\lambda = \frac{1.9878 \times 10^{-25}}{4.0881 \times 10^{-19}} = 4.87 \times 10^{-7}\,\mathrm{m}$$

Therefore, the wavelength of the radiation emitted is $\lambda = 487\,\mathrm{nm}$.

Quick Tip

The wavelength of radiation emitted during an electronic transition can be calculated using the energy-wavelength relation. Don't forget to convert the energy from eV to joules before using the formula.

---

20. (b) In which series of hydrogen spectrum does this line fall?

Correct Answer: The line falls in the Balmer series of the hydrogen spectrum.

Solution: Step 1: The wavelength of the emitted radiation corresponds to a specific transition in the hydrogen atom. Based on the energy difference between the levels, we can identify the series of the hydrogen spectrum.

Step 2: The energy levels of the hydrogen atom are given by the formula:

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

where n is the principal quantum number.

Step 3: The energy difference between two levels, say n_1 and n_2, is given by:

$$\Delta E = E_{n_1} - E_{n_2} = 13.6\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)\text{ eV}$$

Step 4: The transition that corresponds to the wavelength $486\,\text{nm}$ is associated with the $n_2 = 3$ and $n_1 = 2$ levels of the hydrogen atom. This is part of the Balmer series, which involves transitions from higher levels (with $n_2 \geq 3$) to $n_1 = 2$.

Step 5: Since the wavelength 486 nm corresponds to this transition, it falls in the Balmer series of the hydrogen spectrum.

Quick Tip

The Balmer series corresponds to transitions where the electron moves to the $n = 2$ energy level from higher levels. The lines of the Balmer series fall in the visible spectrum.

---

21. The Earth revolves around the Sun in an orbit of radius 1.5×10^{11} m with orbital speed 30 km/s. Find the quantum number that characterizes its revolution using Bohr's model in this case (mass of Earth $= 6.0 \times 10^{24}$ kg).

Solution: Step 1: According to Bohr's model, the angular momentum of the Earth in orbit is quantized and is given by:

$$mvr = n\hbar$$

where:

- m is the mass of the Earth,
- v is the orbital speed,

- r is the radius of the orbit,

- n is the quantum number,

- $\hbar = \frac{h}{2\pi}$ is the reduced Planck's constant ($h = 6.626 \times 10^{-34}\,\text{J s}$).

Step 2: Rearranging the equation for n:

$$n = \frac{mvr}{\hbar}$$

Step 3: Substituting the given values:

- $m = 6.0 \times 10^{24}\,\text{kg}$,

- $v = 30\,\text{km/s} = 3.0 \times 10^{4}\,\text{m/s}$,

- $r = 1.5 \times 10^{11}\,\text{m}$,

- $\hbar = 1.055 \times 10^{-34}\,\text{J s}$.

$$n = \frac{(6.0 \times 10^{24})(3.0 \times 10^{4})(1.5 \times 10^{11})}{1.055 \times 10^{-34}}$$
$$n = \frac{2.7 \times 10^{40}}{1.055 \times 10^{-34}} = 2.56 \times 10^{74}$$

Thus, the quantum number n is approximately 2.56×10^{74}.

Quick Tip

Bohr's model for the quantization of angular momentum helps determine the quantum number for large systems like the Earth by using the formula $mvr = n\hbar$.

Section-C

22. (a) Write Einstein's photoelectric equation. How did Millikan prove the validity of this equation?

Solution: Step 1: Einstein's photoelectric equation is given by:

$$E_{\text{kin}} = h\nu - \phi$$

where:

- E_{kin} is the kinetic energy of the emitted photoelectron,

- h is Planck's constant ($6.626 \times 10^{-34}\,\text{J s}$),

- ν is the frequency of the incident radiation,

- ϕ is the work function of the material (the minimum energy required to release an electron from the surface).

This equation expresses the energy conservation in the photoelectric effect: the energy of the incoming photons is used to overcome the work function, and the excess energy is imparted as kinetic energy to the emitted electron.

Step 2: Millikan's experiment validated this equation by measuring the stopping potential required to stop the emitted photoelectrons. He measured the maximum kinetic energy of the photoelectrons for various frequencies of incident light, which allowed him to confirm the linear relationship between the kinetic energy and frequency of the incident radiation, as predicted by Einstein's equation.

Quick Tip

Einstein's photoelectric equation provides a direct relationship between the energy of the incident light, the work function of the material, and the kinetic energy of the emitted electrons. Millikan confirmed the validity by his precise measurements of stopping potential and electron energy.

---

22. (b) Explain the existence of threshold frequency of incident radiation for photoelectric emission from a given surface.

Solution: Step 1: The threshold frequency (ν_{th}) is the minimum frequency of incident radiation required to emit photoelectrons from a given surface. This frequency corresponds to the minimum energy required to overcome the work function (ϕ) of the material.

Step 2: According to Einstein's photoelectric equation:

$$E_{\text{photon}} = h\nu$$

where E_{photon} is the energy of the incoming photon. For photoelectric emission to occur, the energy of the photon must be greater than or equal to the work function of the material, ϕ:

$$h\nu \geq \phi$$

Step 3: The threshold frequency ν_{th} corresponds to the minimum frequency at which this condition is satisfied, i.e. when $h\nu_{\text{th}} = \phi$. Thus, the threshold frequency is given by:

$$\nu_{\text{th}} = \frac{\phi}{h}$$

Step 4: If the frequency of the incident radiation is lower than the threshold frequency, the energy of the photons is insufficient to overcome the work function, and no photoelectrons are emitted.

Quick Tip

The threshold frequency is the minimum frequency required to release photoelectrons from a material. Below this frequency, photons do not have enough energy to overcome the work function.

---

23. (a) Define the term 'electric flux' and write its dimensions.

Solution: Step 1: Electric flux is defined as the product of the electric field and the area through which the field lines pass, and it is given by:

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

where $\vec{E}$ is the electric field and $\vec{A}$ is the area vector.

Step 2: The electric flux through a surface is also given by:

$$\Phi_E = EA\cos\theta$$

where E is the magnitude of the electric field, A is the area of the surface, and θ is the angle between the electric field and the normal to the surface.

Step 3: The dimensions of electric flux can be derived by considering the units of electric field (N/C) and area (m^2). The dimensions of electric flux are:

$$[\Phi_E] = [E] \times [A] = \left[\frac{\text{N}}{\text{C}}\right] \times \left[\text{m}^2\right]$$

Using the dimensions of force (M L T^{-2}) and charge (A s), the dimensions of electric flux are:

$$[\Phi_E] = \mathrm{M\,L^3T^{-3}A^{-1}}$$

Quick Tip

Electric flux represents the number of electric field lines passing through a surface. Its dimensions are derived from the electric field and area.

---

23. (b) A plane surface, in the shape of a square of side 1 cm, is placed in an electric field $\vec{E} = (100\,\text{N/C})\hat{i}$ such that the unit vector normal to the surface is given by $\hat{n} = 0.8\hat{i} + 0.6\hat{k}$. Find the electric flux through the surface.

Solution: Step 1: The electric flux through the surface is given by the formula:

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

where $\vec{A} = A\hat{n}$ is the area vector. Since the surface is square with side length 1 cm, the area is:

$$A = (1\,\text{cm})^2 = 1 \times 10^{-4}\,\text{m}^2$$

Step 2: The electric flux is:

$$\Phi_E = EA\cos\theta$$

where $E = 100\,\text{N/C}$, $A = 1 \times 10^{-4}\,\text{m}^2$, and θ is the angle between the electric field vector and the unit normal vector to the surface.

Step 3: To find $\cos\theta$, we use the dot product of $\vec{E}$ and $\hat{n}$:

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

$$\vec{E} = 100\,\hat{\imath}\,\text{N/C}, \quad \hat{n} = 0.8\hat{i} + 0.6\hat{k}$$

$$\vec{E} \cdot \hat{n} = (100)(0.8) + (0)(0.6) = 80$$

$$|\vec{E}| = 100\,\text{N/C}$$

$$\cos\theta = \frac{80}{100} = 0.8$$

Step 4: Now, calculate the electric flux:

$$\Phi_E = 100 \times 1 \times 10^{-4} \times 0.8 = 8 \times 10^{-3}\,\text{N m}^2/\text{C}$$

Thus, the electric flux through the surface is $8 \times 10^{-3}\,\text{N m}^2/\text{C}$.

Quick Tip

The electric flux depends on the angle between the electric field and the normal to the surface. For maximum flux, the field is normal to the surface.

---

24. (a) (i) State Lenz's Law. In a closed circuit, the induced current opposes the change in magnetic flux that produced it as per the law of conservation of energy. Justify.

Solution: Step 1: Lenz's Law states that the direction of the induced current in a conductor is such that it opposes the change in magnetic flux that produces it. This is a manifestation of the law of conservation of energy.

Step 2: The opposition to the change in magnetic flux is due to the fact that if the induced current did not oppose the flux change, it would result in a continuous increase in energy without any mechanism to stop the increase. This would violate the principle of conservation of energy. The induced current creates a magnetic field that opposes the original flux change, thus ensuring energy is conserved.

Quick Tip

Lenz's Law ensures that the induced current opposes the change in flux, maintaining the law of conservation of energy and preventing infinite energy generation.

---

24. (a) (ii) A metal rod of length 2 m is rotated with a frequency of 60 rev/s about an axis passing through its centre and perpendicular to its length. A uniform magnetic field of 2T perpendicular to its plane of rotation is switched-on in the region. Calculate the e.m.f. induced between the centre and the end of the rod.

Solution: Given:

- Magnetic field $B = 2$

- Length of the rod $L = 2$
- Frequency of rotation $f = 60$

The angular velocity ω is given by:

$$\omega = 2\pi f$$

Substituting the value of $f = 60\,\text{rev/s}$:

$$\omega = 2\pi \times 60 = 120\pi\,\text{rad/s}$$

The induced e.m.f. $\mathcal{E}$ is given by:

$$\mathcal{E} = \frac{1}{2}BL^2\omega$$

Substituting the known values:

$$\mathcal{E} = \frac{1}{2} \times 2 \times (2)^2 \times (2\pi \times 60)$$

$$\mathcal{E} = \frac{1}{2} \times 2 \times 4 \times 120\pi$$

$$\mathcal{E} = 480\pi\,\text{V}$$

Finally, calculating the value of $\mathcal{E}$ using $\pi \approx 3.1416$:

$$\mathcal{E} = 480 \times 3.1416\,\text{V} \approx 1.51 \times 10^3\,\text{V}$$

$\boxed{\mathcal{E} = 1.51 \times 10^3\,\text{V}}$

Quick Tip

The induced e.m.f. in a rotating rod in a magnetic field depends on the magnetic field strength, the frequency of rotation, and the length of the rod.

---

24. (b) (i) State and explain Ampere's circuital law.

Solution: Step 1: Ampere's circuital law states that the line integral of the magnetic field $\vec{B}$ around a closed loop is proportional to the total current I_{enc} enclosed by the loop. Mathematically, it is expressed as:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enc}}$$

where:

$\oint \vec{B} \cdot d\vec{l}$ is the line integral of the magnetic field around a closed loop,

μ_0 is the permeability of free space ($\mu_0 = 4\pi \times 10^{-7}\,\text{N/A}^2$),

I_{enc} is the total current enclosed by the loop.

Step 2: The law implies that the magnetic field around a current-carrying conductor is directly proportional to the current flowing through the conductor. It is commonly used to determine the magnetic field around simple geometries like straight wires, solenoids, and loops.

Quick Tip

Ampere's circuital law is a fundamental law of electromagnetism that helps in calculating the magnetic field produced by current-carrying conductors using symmetry and geometry.

---

24. (b) (ii) Two long straight parallel wires separated by 20 cm carry 5 A and 10 A current respectively, in the same direction. Find the magnitude and direction of the net magnetic field at a point midway between them.

Solution: Step 1: The magnetic field B at a point due to a long straight current-carrying conductor is given by Ampere's law:

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

where:

B is the magnetic field at a distance r from the wire,

I is the current in the wire,

r is the distance from the wire,

μ_0 is the permeability of free space ($\mu_0 = 4\pi \times 10^{-7}\,\text{N/A}^2$).

Step 2: For two wires carrying currents in the same direction, the magnetic field due to each wire at a point midway between them (which is at a distance $r = 10\,\text{cm} = 0.1\,\text{m}$ from each wire) can be calculated using the formula above.

For the first wire with current $I_1 = 5\,\text{A}$:

$$B_1 = \frac{\mu_0 I_1}{2\pi r} = \frac{(4\pi \times 10^{-7}) \times 5}{2\pi \times 0.1} = 1 \times 10^{-5}\,\text{T}$$

For the second wire with current $I_2 = 10\,\text{A}$:

$$B_2 = \frac{\mu_0 I_2}{2\pi r} = \frac{(4\pi \times 10^{-7}) \times 10}{2\pi \times 0.1} = 2 \times 10^{-5}\,\text{T}$$

Step 3: Since the currents are in the same direction, the magnetic fields due to the two wires at the midway point will be in opposite directions. Therefore, the net magnetic field at the point midway between the wires is the difference between the two fields:

$$B_{\text{net}} = B_2 - B_1 = 2 \times 10^{-5} - 1 \times 10^{-5} = 1 \times 10^{-5}\,\text{T}$$

Step 4: The direction of the magnetic field can be determined by using the right-hand rule. The magnetic field due to the first wire is directed into the page, and the magnetic field due to the second wire is directed out of the page. Since the fields are in opposite directions, the net magnetic field will be directed out of the page.

Thus, the magnitude of the net magnetic field is $1 \times 10^{-5}\,\text{T}$, and the direction is out of the page.

Quick Tip

When calculating the magnetic field due to parallel currents, use Ampere's law and apply the right-hand rule to determine the direction of the field. The fields due to currents in the same direction will oppose each other.

---

25. An electron moving with a velocity $\vec{v} = (1.0 \times 10^7\,\textbf{m/s})\hat{\imath} + (0.5 \times 10^7\,\textbf{m/s})\hat{\jmath}$ enters a region of uniform magnetic field $\vec{B} = (0.5\,\textbf{mT})\hat{\jmath}$. Find the radius of the circular path described by it. While rotating, does the electron trace a linear path too? If so, calculate the linear distance covered by it during the period of one revolution.

Solution: Given Data

- Velocity of the electron, $\vec{v} = (1.0 \times 10^7\,\text{m/s})\hat{\imath} + (0.5 \times 10^7\,\text{m/s})\hat{\jmath}$
- Magnetic field, $\vec{B} = (0.5\,\text{mT})\hat{\jmath} = (0.5 \times 10^{-3}\,\text{T})\hat{\jmath}$

Magnetic Force

The magnetic force $\vec{F}$ on a moving charge is given by:

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

For an electron, $q = -e$, where e is the elementary charge ($e \approx 1.6 \times 10^{-19}$ C).

The cross product $\vec{v} \times \vec{B}$ is:

$$\vec{v} \times \vec{B} = (1.0 \times 10^7\,\hat{\imath} + 0.5 \times 10^7\,\hat{\jmath}) \times (0.5 \times 10^{-3}\,\hat{\jmath})$$

$$= 1.0 \times 10^7 \times 0.5 \times 10^{-3}(\hat{\imath} \times \hat{\jmath}) + 0.5 \times 10^7 \times 0.5 \times 10^{-3}(\hat{\jmath} \times \hat{\jmath})$$

$$= 5.0 \times 10^3(\hat{k}) + 0$$

$$= 5.0 \times 10^3\,\hat{k}\,\text{m/s} \cdot \text{T}$$

Therefore, the force is:

$$\vec{F} = -e(5.0 \times 10^3\,\hat{k}) = -5.0 \times 10^3 e\,\hat{k}\,\text{N}$$

Radius of Circular Path

The centripetal force required for circular motion is provided by the magnetic force:

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

where m is the mass of the electron ($m \approx 9.11 \times 10^{-31}$ kg) and v is the component of velocity perpendicular to $\vec{B}$.

The perpendicular component of velocity is $v_\perp = 1.0 \times 10^7$ m/s.

Equating the magnetic force to the centripetal force:

$$ev_\perp B = \frac{mv_\perp^2}{r}$$

$$r = \frac{mv_\perp}{eB}$$

$$r = \frac{9.11 \times 10^{-31} \times 1.0 \times 10^7}{1.6 \times 10^{-19} \times 0.5 \times 10^{-3}}$$

$$r = \frac{9.11 \times 10^{-24}}{0.8 \times 10^{-22}}$$

$$r = 0.1139\,\text{m}$$

Linear Distance Covered

The electron also has a velocity component parallel to the magnetic field ($v_{\parallel} = 0.5 \times 10^7$ m/s), which causes it to move linearly along the field direction.

The time period T for one revolution is:

$$T = \frac{2\pi r}{v_{\perp}} = \frac{2\pi \times 0.1139}{1.0 \times 10^7}$$

$$T \approx 7.16 \times 10^{-8}\,\text{s}$$

The linear distance d covered during one revolution is:

$$d = v_{\parallel} \times T = 0.5 \times 10^7 \times 7.16 \times 10^{-8}$$

$$d \approx 0.358\,\text{m}$$

Final Answer

- The radius of the circular path is approximately $0.114\,\text{m}$.
- The electron traces a helical path, and the linear distance covered during one revolution is approximately $0.358\,\text{m}$.

Quick Tip

When a charged particle moves in a magnetic field, it follows a circular path, and the radius of this path depends on the velocity, charge, and magnetic field. The linear distance covered during one revolution is the circumference of the circle.

26. (a) (i) Name the parts of the electromagnetic spectrum which are also known as ‘heat waves’.

Solution: Step 1: Infrared radiation is the part of the electromagnetic spectrum that is commonly referred to as ’heat waves’. This is because infrared radiation is primarily responsible for transferring heat energy.

Step 2: Infrared radiation has wavelengths longer than visible light but shorter than microwaves, typically ranging from $700\,\text{nm}$ to $1\,\text{mm}$. When absorbed by an object, it increases the thermal energy of that object, which is why it is associated with heat.

Quick Tip

Infrared radiation is emitted by all objects depending on their temperature. It is commonly used in thermal imaging and heating applications.

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26. (a) (ii) Name the parts of the electromagnetic spectrum which are absorbed by the ozone layer in the atmosphere.

Solution: Step 1: The ozone layer in the Earth's atmosphere absorbs the majority of ultraviolet (UV) radiation from the Sun, particularly UV-B and UV-C rays.

Step 2: UV-A rays, however, pass through the ozone layer and reach the Earth's surface. The absorption of UV-B and UV-C rays by the ozone layer helps protect living organisms from harmful radiation.

Quick Tip

The ozone layer acts as a shield, absorbing harmful UV radiation and preventing it from reaching the Earth's surface, where it can cause damage to skin, eyes, and DNA.

---

26. (b) Write briefly one method each, of the production and detection of these radiations.

Solution: Step 1:

Production of Infrared Radiation: Infrared radiation is produced by heating an object or through the vibration of molecules. A common method of producing infrared radiation is by using an infrared lamp, which heats a filament to emit infrared radiation.

Detection of Infrared Radiation: Infrared radiation can be detected using an infrared sensor or an infrared camera, which measures the heat emitted by objects.

Step 2:

Production of Ultraviolet Radiation: UV radiation is typically produced by special UV lamps or mercury vapor lamps, which emit UV light when an electric current passes through a gas or vapor.

Detection of Ultraviolet Radiation: UV radiation can be detected using UV detectors or by observing its effects, such as fluorescence in certain materials. UV-sensitive photographic plates or photodetectors can also be used for this purpose.

Quick Tip

Infrared radiation is commonly detected using thermal imaging techniques, while ultraviolet radiation detection often involves fluorescence or special photodetectors sensitive to UV wavelengths.

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27. (a) Explain the characteristics of a p-n junction diode that makes it suitable for its use as a rectifier.

Solution: Step 1: A p-n junction diode has two main characteristics that make it suitable for use as a rectifier:

Unidirectional Current Flow: When forward biased, the diode allows current to flow easily through it, while when reverse biased, it blocks the current almost completely. This ability to conduct current in only one direction makes the p-n junction diode ideal for converting alternating current (AC) to direct current (DC).

Threshold Voltage: A diode requires a minimum voltage (called the ”threshold” or ”cut-in” voltage, typically 0.7 V for silicon diodes) to allow current to pass through when forward biased. Below this voltage, the diode does not conduct, which helps in blocking the reverse current.

Step 2: Due to these characteristics, the p-n junction diode can be used in rectifiers to convert AC into DC, as it only allows the current to pass in one direction, thus removing the negative half of the AC signal.

Quick Tip

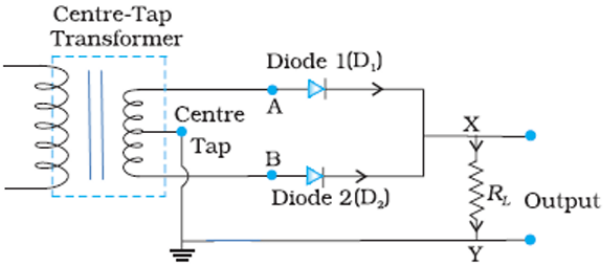
The key property of a p-n junction diode that makes it a good rectifier is its ability to only allow current to flow in one direction when forward biased and block current when reverse biased.

---

27. (b) With the help of a circuit diagram, explain the working of a full wave rectifier.

Solution: Step 1: A full wave rectifier is a circuit that converts both the positive and negative halves of an AC signal into a pulsating DC signal. It uses two diodes, which conduct during alternate half cycles of the input AC signal.

Step 2: Circuit diagram for a full wave rectifier:



Step 3: Working of the Full Wave Rectifier:

During the positive half cycle of the input AC, diode D_1 is forward biased and conducts, allowing current to flow through the load resistor in one direction.

During the negative half cycle of the AC input, diode D_2 becomes forward biased and conducts, reversing the direction of current through the load resistor but still allowing current to flow in the same direction as in the positive half cycle.

The result is a pulsating DC output with both halves of the input AC waveform contributing to the output.

Step 4: The output of the full wave rectifier is a unidirectional pulsating signal that can be smoothed using a filter (typically a capacitor) to obtain a steady DC signal.

Quick Tip

In a full wave rectifier, both halves of the AC input signal are used, resulting in higher average output voltage compared to a half-wave rectifier.

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28. Explain the following,giving reasons:

(a) A doped semiconductor is electrically neutral.

Solution: A doped semiconductor is obtained by adding impurities to an intrinsic semiconductor. The impurities add extra electrons (n-type doping) or create holes (p-type doping), but the number of positive charges (protons) in the semiconductor remains unchanged.

Even though doping introduces additional free charge carriers (electrons or holes), the number of positive and negative charges are balanced in the overall semiconductor. As a result, the net charge of the doped semiconductor remains zero, making it electrically neutral.

Quick Tip

Doping a semiconductor introduces charge carriers, but the total number of positive and negative charges remains balanced, ensuring electrical neutrality.

(b) In a p-n junction under equilibrium, there is no net current.

Solution: In a p-n junction, when the junction is formed, free electrons from the n-type region diffuse into the p-type region, and holes from the p-type region diffuse into the n-type region. This movement creates a region called the depletion region where no free charge carriers exist.

As a result of this diffusion, an electric field is set up across the depletion region, which opposes further diffusion of charge carriers. This creates a state of equilibrium where the drift current (due to the electric field) exactly cancels out the diffusion current. Hence, no net current flows through the junction under equilibrium.

Quick Tip

Under equilibrium conditions, the diffusion current of charge carriers is exactly balanced by the drift current due to the electric field, resulting in no net current in a p-n junction.

(c) In a diode, the reverse current is practically not dependent on the applied voltage.

Solution: In a p-n junction diode, when a reverse voltage is applied, very few charge carriers (electrons and holes) are available to conduct current. As a result, the reverse current is extremely small and is often referred to as the leakage current.

The reverse current is practically independent of the applied reverse voltage, except when the reverse voltage exceeds the breakdown voltage of the diode, at which point the reverse current increases dramatically (due to avalanche or Zener breakdown).

Step 3: For most practical purposes, the reverse current remains almost constant and very small, even with increasing reverse voltage, as long as the applied voltage does not exceed the breakdown voltage.

Quick Tip

In reverse bias, the current is negligible and does not change significantly with increasing reverse voltage, except when the breakdown voltage is reached.

Section-D

29. Dielectrics play an important role in the design of capacitors. The molecules of a dielectric may be polar or non-polar. When a dielectric slab is placed in an external electric field, opposite charges appear on the two surfaces of the slab perpendicular to the electric field. Due to this, an electric field is established inside the dielectric.
The capacitance of a capacitor is determined by the dielectric constant of the material that fills the space between the plates. Consequently, the energy storage capacity of a capacitor is also affected. Like resistors, capacitors can also be arranged in series and/or parallel.

29. (i) Which of the following is a polar molecule?

(A) O_2

(B) H_2

(C) N_2

(D) HCl

Correct Answer: (D) HCl

Solution: Step 1: Polar molecules have a permanent dipole moment due to the unequal sharing of electrons between atoms in the molecule, leading to a positive and a negative end.

Step 2: Among the options, HCl is a polar molecule because chlorine is more electronegative than hydrogen, which causes an uneven distribution of electron density, creating a dipole moment. The other molecules (O_2, H_2, N_2) are non-polar because the electron distribution is symmetric in these molecules.

Quick Tip

Polar molecules have a permanent dipole moment, while non-polar molecules have symmetric electron distribution with no dipole moment.

---

29. (ii) Which of the following statements about dielectrics is correct?

(A) A polar dielectric has a net dipole moment in absence of an external electric field, which gets modified due to the induced dipoles.

(B) The net dipole moments of induced dipoles are along the direction of the applied electric field.

(C) Dielectrics contain free charges.

(D) The electric field produced due to induced surface charges inside a dielectric is along the external electric field.

Correct Answer: (B) The net dipole moments of induced dipoles are along the direction of the applied electric field.

Solution: Step 1: In a dielectric material, when an external electric field is applied, it induces a separation of charges within the molecules, causing the dipoles to align with the electric field. This results in the net dipole moment of induced dipoles being along the direction of the applied electric field.

Step 2: The other options are incorrect:

- Option (A) is incorrect because, in the absence of an external electric field, a polar dielectric already has a net dipole moment.

- Option (C) is incorrect because dielectrics do not contain free charges; they are insulators with bound charges that respond to an external electric field.

- Option (D) is incorrect because the electric field due to the induced surface charges opposes the applied electric field inside the dielectric.

Quick Tip

In dielectrics, the induced dipoles align with the applied electric field, creating an opposing electric field that reduces the field inside the material.

---

29. (iii) When a dielectric slab is inserted between the plates of an isolated charged capacitor, the energy stored in it:

(A) increases and the electric field inside it also increases.

(B) decreases and the electric field also decreases.

(C) decreases and the electric field increases.

(D) increases and the electric field decreases.

Correct Answer: (B) decreases and the electric field also decreases.

Solution: Step 1: When a dielectric slab is inserted between the plates of a charged capacitor, the capacitance increases due to the dielectric constant κ of the material. The energy stored in a capacitor is given by:

$$U = \frac{Q^2}{2C}$$

where Q is the charge and C is the capacitance. Since the capacitor is isolated, the charge remains constant, and increasing the capacitance leads to a decrease in the energy stored.

Step 2: The electric field inside the capacitor also decreases because the dielectric reduces the effective field between the plates. The dielectric polarizes and partially cancels the electric field created by the charges on the plates.

Step 3: Therefore, the energy stored decreases and the electric field also decreases.

Quick Tip

Inserting a dielectric increases the capacitance of a capacitor, which reduces the energy stored if the charge is constant. The dielectric also reduces the electric field inside the capacitor.

---

29. (iv) (a) An air-filled capacitor with plate area A and plate separation d has capacitance C_0. A slab of dielectric constant K, area A and thickness $\frac{d}{5}$ is inserted between the plates. The capacitance of the capacitor will become:

(A) $\left[\frac{4K}{5K+1}\right] C_0$

(B) $\left[\frac{K+5}{4}\right] C_0$

(C) $\left[\frac{5K}{4K+1}\right] C_0$

(D) $\left[\frac{K+4}{5K}\right] C_0$

Correct Answer: (C) $\left[\frac{5K}{4K+1}\right] C_0$

Solution: Step 1: The capacitance of a parallel plate capacitor without any dielectric is given by:

$$C_0 = \epsilon_0 \frac{A}{d}$$

where ϵ_0 is the permittivity of free space, A is the area of the plates, and d is the separation between the plates.

Step 2: When a dielectric material with dielectric constant K is inserted between the plates, the capacitance increases by a factor of K, but only for the portion of the plate that is covered by the dielectric. In this case, the dielectric slab occupies $\frac{d}{5}$ of the total plate separation d.

Step 3: The new capacitance is given by the sum of the capacitance of the dielectric-filled region and the air-filled region:

$$C = \frac{\epsilon_0 A}{d - \frac{d}{5}} + \frac{\epsilon_0 K A}{\frac{d}{5}}$$

Simplifying this expression:

$$C = \frac{\epsilon_0 A}{\frac{4d}{5}} + \frac{\epsilon_0 K A}{\frac{d}{5}} = \frac{5\epsilon_0 A}{4d} + \frac{5K\epsilon_0 A}{d}$$

Step 4: Now, factoring out the common term $\frac{\epsilon_0 A}{d}$, we get:

$$C = \frac{\epsilon_0 A}{d}\left(\frac{5}{4} + 5K\right) = C_0\left(\frac{5}{4} + 5K\right)$$

Step 5: Therefore, the new capacitance is:

$$C = C_0\left[\frac{5K}{4K+1}\right]$$

Thus, the capacitance of the capacitor becomes $\left[\frac{5K}{4K+1}\right] C_0$.

Quick Tip

When a dielectric is inserted into a capacitor, the capacitance increases by a factor of the dielectric constant. The capacitance is determined by the ratio of the thickness of the dielectric region to the total plate separation.

---

29. (iv) (b) Two capacitors of capacitances $2C_0$ and $6C_0$, are first connected in series and then in parallel across the same battery. The ratio of energies stored in series combination to that in parallel is:

(A) $\frac{1}{4}$

(B) $\frac{1}{6}$

(C) $\frac{2}{15}$

(D) $\frac{3}{16}$

Correct Answer: (D) $\frac{3}{16}$

Solution: Let the battery voltage be V.

Energy Stored in a Capacitor:

The energy stored in a capacitor is given by the formula:

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

where C is the capacitance and V is the voltage across the capacitor.

Energy Stored in Series Combination:

For capacitors connected in series, the equivalent capacitance $C_{\text{eq, series}}$ is given by:

$$\frac{1}{C_{\text{eq, series}}} = \frac{1}{C_1} + \frac{1}{C_2}$$

where:

$C_1 = 2C_0$,

$C_2 = 6C_0$.

Substituting the values:

$$\frac{1}{C_{\text{eq, series}}} = \frac{1}{2C_0} + \frac{1}{6C_0} = \frac{3}{6C_0} + \frac{1}{6C_0} = \frac{4}{6C_0}$$

Thus:

$$C_{\text{eq, series}} = \frac{6C_0}{4} = 1.5C_0$$

The energy stored in the series combination is:

$$E_{\text{series}} = \frac{1}{2}C_{\text{eq, series}}V^2 = \frac{1}{2} \times 1.5C_0 \times V^2 = 0.75C_0V^2$$

Energy Stored in Parallel Combination:

For capacitors connected in parallel, the equivalent capacitance $C_{\text{eq, parallel}}$ is given by:

$$C_{\text{eq, parallel}} = C_1 + C_2$$

Substituting the values:

$$C_{\text{eq, parallel}} = 2C_0 + 6C_0 = 8C_0$$

The energy stored in the parallel combination is:

$$E_{\text{parallel}} = \frac{1}{2}C_{\text{eq, parallel}}V^2 = \frac{1}{2} \times 8C_0 \times V^2 = 4C_0V^2$$

Ratio of Energies:

The ratio of the energy stored in the series combination to that in the parallel combination is:

$$\text{Ratio} = \frac{E_{\text{series}}}{E_{\text{parallel}}} = \frac{0.75C_0V^2}{4C_0V^2} = \frac{0.75}{4} = \frac{3}{16}$$

Thus, the ratio of energies stored in series combination to that in parallel is $\frac{3}{16}$.

Correct Answer: (D) $\frac{3}{16}$

Quick Tip

The energy stored in a capacitor depends on its capacitance. When capacitors are connected in series, the equivalent capacitance is smaller, while in parallel, it is larger, affecting the energy stored.

---

30. A prism is an optical medium bounded by three refracting plane surfaces. A ray of light suffers successive refractions on passing through its two surfaces and deviates by a certain angle from its original path. The refractive index of the material of the prism is given by

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

If the angle of incidence on the second surface is greater than an angle called the critical angle, the ray will not be refracted from the second surface and is totally internally reflected.

30. (i) The critical angle for glass is θ_1 and that for water is θ_2. The critical angle for the glass-water surface would be (given $\mu_g = 1.5$, $\mu_w = 1.33$):

(A) less than θ_2

(B) between θ_1 and θ_2

(C) greater than θ_2

(D) less than θ_1

Correct Answer: (C) greater than

Solution: Given Data

- Refractive index of glass, $\mu_g = 1.5$
- Refractive index of water, $\mu_w = 1.33$
- Critical angle for glass, θ_1
- Critical angle for water, θ_2

Critical Angle Formula

The critical angle θ_c for a boundary between two media is given by:

$$\sin\theta_c = \frac{\mu_2}{\mu_1}$$

where μ_1 is the refractive index of the denser medium (glass) and μ_2 is the refractive index of the less dense medium (water).

Critical Angle for Glass-Water Interface

For the glass-water interface:

$$\sin\theta_c = \frac{\mu_w}{\mu_g} = \frac{1.33}{1.5} \approx 0.8867$$

Therefore:

$$\theta_c = \sin^{-1}(0.8867) \approx 62.5^\circ$$

Comparison with Given Critical Angles

- The critical angle for glass (θ_1) is:

$$\sin\theta_1 = \frac{1}{\mu_g} = \frac{1}{1.5} \approx 0.6667 \Rightarrow \theta_1 \approx 41.8^\circ$$

- The critical angle for water (θ_2) is:

$$\sin\theta_2 = \frac{1}{\mu_w} = \frac{1}{1.33} \approx 0.7519 \Rightarrow \theta_2 \approx 48.8^\circ$$

The critical angle for the glass-water interface ($\theta_c \approx 62.5^\circ$) is greater than both θ_1 and θ_2.

Conclusion

The critical angle for the glass-water interface is greater than the critical angle for water (θ_2).

Final Answer

$$\boxed{\text{(C) greater than } \theta_2}$$

Quick Tip

The critical angle for a boundary between two media depends on the refractive indices of the two media. The critical angle for the boundary between glass and water lies between the critical angles for each medium individually.

---

30. (ii) When a ray of light of wavelength λ and frequency ν is refracted into a denser medium,

(A) λ and ν both increase.

(B) λ increases but ν is unchanged.

(C) λ decreases but ν is unchanged.

(D) λ and ν both decrease.

Correct Answer: (C) λ decreases but ν is unchanged.

Solution: Step 1: When light enters a denser medium, its speed decreases due to the higher refractive index μ. The relationship between the speed of light v, wavelength λ, and frequency ν is given by:

$$v = \lambda\nu$$

Since the frequency ν remains unchanged when light passes from one medium to another, the decrease in speed v leads to a decrease in the wavelength λ.

Step 2: The refractive index μ of the denser medium is greater than 1, and since the speed of light decreases in the denser medium, the wavelength also decreases.

Conclusion: The wavelength λ decreases while the frequency ν remains unchanged.

Quick Tip

When light refracts into a denser medium, its speed decreases, which leads to a decrease in wavelength. The frequency, however, remains the same.

---

30. (iii) (a) The critical angle for a ray of light passing from glass to water is minimum for

(A) red colour

(B) blue colour

(C) yellow colour

(D) violet colour

Correct Answer: (D) violet colour

Solution: Step 1: The critical angle θ_c is given by the formula:

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

where n_1 and n_2 are the refractive indices of the two media.

Step 2: The refractive index of a medium depends on the wavelength of light. Violet light has a shorter wavelength than red light and thus a higher refractive index. As a result, the critical angle for violet light is smaller than for red light.

Step 3: Since the critical angle is inversely proportional to the refractive index, the critical angle is minimum for violet light (the shortest wavelength).

Conclusion: The critical angle for a ray of light passing from glass to water is minimum for violet colour.

Quick Tip

The critical angle for different colours of light depends on their wavelength. Shorter wavelengths (such as violet) result in smaller critical angles.

---

30. (iii) (b) Three beams of red, yellow, and violet colours are passed through a prism, one by one under the same condition. When the prism is in the position of minimum deviation, the angles of refraction from the second surface are r_R, r_Y, and r_V

respectively. Then,

(A) $r_V < r_Y < r_R$

(B) $r_Y < r_R < r_V$

(C) $r_R < r_Y < r_V$

(D) $r_R = r_Y = r_V$

Correct Answer: (C) $r_R < r_Y < r_V$

Solution: Step 1: When white light passes through a prism, different wavelengths of light experience different amounts of deviation due to their different refractive indices in the prism material. Violet light, having the shortest wavelength, is refracted the most, and red light, with the longest wavelength, is refracted the least.

Step 2: The angle of refraction in a prism depends on the refractive index, which in turn depends on the wavelength of light. The refractive index decreases as the wavelength increases.

Step 3: Since the violet light has the highest refractive index, it will have the smallest angle of refraction r_V. The red light, with the lowest refractive index, will have the largest angle of refraction r_R. Yellow light lies in between, with an angle of refraction r_Y.

Step 4: Therefore, the order of angles of refraction is $r_R < r_Y < r_V$.

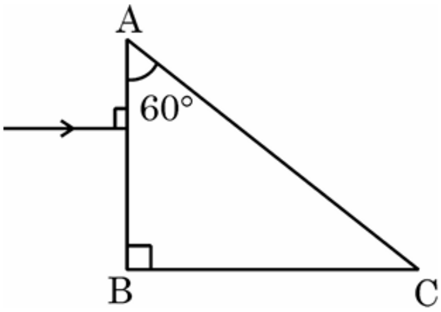
Conclusion: The correct option is (C) $r_R < r_Y < r_V$.

Quick Tip

The angle of refraction for different colours of light passing through a prism varies with the refractive index, which is greater for shorter wavelengths (violet) and lower for longer wavelengths (red).

---

30. (iv) A ray of light is incident normally on a prism ABC of refractive index $\sqrt{2}$, as shown in the figure. After it strikes face AC, it will



(A) go straight und deviated

(B) just graze along the face AC

(C) refract and go out of the prism

(D) undergo total internal reflection

Correct Answer: (D) undergo total internal reflection

Solution: Step 1: The ray of light is incident normally on the prism at point B, which means that the angle of incidence $i = 0^\circ$ on face AB.

Step 2: After striking face AC, the angle of incidence θ will be equal to the angle $\angle ABC = 60^\circ$ because of the geometry of the prism.

Step 3: The refractive index $\mu = \sqrt{2}$, and for total internal reflection to occur, the angle of incidence at face AC must exceed the critical angle. The critical angle θ_c is given by:

$$\sin\theta_c = \frac{1}{\mu}$$

Substituting $\mu = \sqrt{2}$:

$$\sin\theta_c = \frac{1}{\sqrt{2}} \Rightarrow \theta_c = \sin^{-1}\left(\frac{1}{\sqrt{2}}\right) = 45^\circ$$

Step 4: Since the angle of incidence on face AC is 60°, which is greater than the critical angle 45°, the ray undergoes total internal reflection inside the prism.

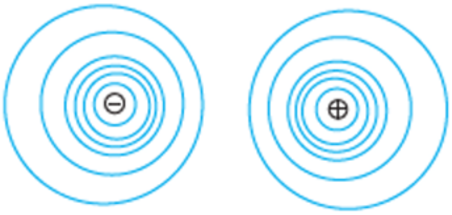
Conclusion: The correct answer is (D) undergo total internal reflection.

Quick Tip

For total internal reflection to occur, the angle of incidence inside the prism must be greater than the critical angle. In this case, the angle is 60°, which is greater than the critical angle of 45°, so total internal reflection occurs.

Section-E

31. (a) (1) Draw equipotential surfaces for an electric dipole.



Solution: Step 1: For an electric dipole, the equipotential surfaces are surfaces on which the electric potential is constant. These surfaces are formed around the dipole, and they are symmetric in nature.

Step 2: The shape of the equipotential surfaces of an electric dipole is more complex than those of a single charge. They are typically shown as two sets of surfaces:

Near the dipole, the surfaces are roughly spherical, but as you move farther away, the surfaces become more elongated, resembling two elongated ovals (along the axis of the dipole).

Step 3: These equipotential surfaces do not intersect each other, and the electric field lines are always perpendicular to the equipotential surfaces.

Quick Tip

Equipotential surfaces are always perpendicular to the electric field lines and are concentric spheres for a point charge. For a dipole, they form a more complex pattern.

---

31. (a) (ii) Two point charges q_1 and q_2, are located at $\vec{r_1}$ and $\vec{r_2}$ respectively in an external electric field $\vec{E}$. Obtain an expression for the potential energy of the system.

Solution: Potential Energy of Two Point Charges in an External Electric Field

Given

- Two point charges q_1 and q_2 located at positions $\vec{r}_1$ and $\vec{r}_2$ respectively.
- An external electric field $\vec{E}$.

Potential Energy Due to External Electric Field

The potential energy of a charge q in an external electric field $\vec{E}$ is:

$$U_{\text{ext}} = q\phi(\vec{r})$$

For the two charges:

$$U_{\text{ext}} = q_1\phi(\vec{r}_1) + q_2\phi(\vec{r}_2)$$

Potential Energy Due to Interaction Between Charges

The potential energy due to the interaction between q_1 and q_2 is:

$$U_{\text{int}} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{|\vec{r}_1 - \vec{r}_2|}$$

Total Potential Energy

The total potential energy U of the system is:

$$U = U_{\text{ext}} + U_{\text{int}}$$

Substituting the expressions:

$$U = q_1\phi(\vec{r}_1) + q_2\phi(\vec{r}_2) + \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{|\vec{r}_1 - \vec{r}_2|}$$

Final Expression The potential energy of the system is:

$$\boxed{U = q_1\phi(\vec{r}_1) + q_2\phi(\vec{r}_2) + \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{|\vec{r}_1 - \vec{r}_2|}}$$

Quick Tip

When charges are placed in an external electric field, the total potential energy of the system includes both the energy due to the electric field and the interaction energy between the charges.

---

31. (a) (iii) The dipole moment of a molecule is 10^{-30} Cm. It is placed in an electric field $\vec{E}$ of 10^5 V/m such that its axis is along the electric field. The direction of $\vec{E}$ is suddenly changed by 60° at an instant. Find the change in the potential energy of the dipole, at that instant.

Solution: Step 1: The potential energy U of an electric dipole in an electric field $\vec{E}$ is given by:

$$U = -\vec{p} \cdot \vec{E}$$

where $\vec{p}$ is the dipole moment and $\vec{E}$ is the electric field.

Step 2: Initially, the dipole moment $\vec{p}$ is aligned with the electric field $\vec{E}$, so the potential energy is:

$$U_i = -pE$$

Step 3: When the direction of the electric field is changed by 60°, the new potential energy becomes:

$$U_f = -pE\cos 60^\circ = -pE \times \frac{1}{2}$$

Step 4: The change in potential energy ΔU is:

$$\Delta U = U_f - U_i = -pE \times \frac{1}{2} - (-pE) = \frac{pE}{2}$$

Step 5: Substituting $p = 10^{-30}$ Cm and $E = 10^5$ V/m:

$$\Delta U = \frac{10^{-30} \times 10^5}{2} = 5 \times 10^{-26}\,\text{J}$$

Thus, the change in potential energy is 5×10^{-26} J.

Quick Tip

The potential energy of a dipole in an electric field depends on the angle between the dipole moment and the electric field. The energy change is proportional to the cosine of the angle between them.

---

31. (b) (i) A thin spherical shell of radius R has a uniform surface charge density ρ. Using Gauss' law, deduce an expression for the electric field:

- (i) Outside the shell.

- (ii) Inside the shell.

Solution: Step 1: Consider a thin spherical shell with a uniform surface charge density ρ and radius R. The total charge Q on the shell is given by:

$$Q = \rho \cdot 4\pi R^2$$

Step 2: Using Gauss' law, we consider a spherical Gaussian surface of radius r, with $r > R$ (outside the shell). The electric flux through the surface is given by:

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

Since the charge is uniformly distributed on the shell, the electric field at any point outside the shell will be radially symmetric, and we can simplify the left-hand side as:

$$E \cdot 4\pi r^2 = \frac{Q}{\epsilon_0}$$

Thus, the electric field outside the shell is:

$$E = \frac{Q}{4\pi \epsilon_0 r^2}$$

Substituting $Q = \rho \cdot 4\pi R^2$, we get:

$$E = \frac{\rho \cdot R^2}{\epsilon_0 r^2}$$

Step 3: Now, consider the electric field inside the shell. For $r < R$, by Gauss' law, the charge enclosed by the Gaussian surface is zero, because there is no charge inside the shell.

Therefore, the electric field inside the shell is:

$$E = 0$$

Conclusion: - (i) The electric field outside the shell is $E = \frac{\rho \cdot R^2}{\epsilon_0 r^2}$

- (ii) The electric field inside the shell is $E = 0$

Quick Tip

Using Gauss' law, the electric field inside a spherical shell is zero, while outside it behaves as if the entire charge were concentrated at the center.

31. (b) (ii) Two long straight thin wires AB and CD have linear charge densities 10 mC/m and -20 mC/m, respectively. They are kept parallel to each other at a distance of 1 m. Find the magnitude and direction of the net electric field at a point midway between them.

Solution: The electric field due to a long straight charged wire with a linear charge density λ at a distance r from it is given by the formula:

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

where:

$\lambda_1 = 10\,\mu\text{C/m} = 10 \times 10^{-6}\,\text{C/m}$ (charge density of wire AB),

$\lambda_2 = -20\,\mu\text{C/m} = -20 \times 10^{-6}\,\text{C/m}$ (charge density of wire CD),

$r = 0.5\,\text{m}$ (distance from the point to each wire), $\epsilon_0 = 8.85 \times 10^{-12}\,\text{C}^2/\text{N m}^2$ is the permittivity of free space.

The net electric field at the midpoint between the two wires is the vector sum of the fields due to each wire. Let's calculate the electric fields E_1 and E_2 at the midpoint:

$$E_1 = \frac{\lambda_1}{2\pi\epsilon_0 r} = \frac{10 \times 10^{-6}}{2\pi(8.85 \times 10^{-12})(0.5)} = 3.59 \times 10^6\,\text{N/C}$$

$$E_2 = \frac{\lambda_2}{2\pi\epsilon_0 r} = \frac{-20 \times 10^{-6}}{2\pi(8.85 \times 10^{-12})(0.5)} = -7.18 \times 10^6\,\text{N/C}$$

Step 1: Calculate the net electric field The direction of the electric fields due to both wires:

The electric field due to wire AB (with λ_1) points away from the wire, toward wire CD.

The electric field due to wire CD (with λ_2) points toward the wire, so it also points toward wire AB.

Since both fields point toward wire CD, the net electric field is the sum of the magnitudes:

$$E_{\text{net}} = E_1 + E_2 = 3.59 \times 10^6 + 7.18 \times 10^6 = 10.77 \times 10^6\,\text{N/C}$$

Thus, the magnitude of the net electric field is:

$$E_{\text{net}} = 10.77 \times 10^6\,\text{N/C}$$

and the direction is toward wire CD (left).

Correct Answer:

The magnitude of the net electric field is 10.77×10^6 N/C. The direction of the net electric field is toward wire CD (left).

Quick Tip

For two parallel charged wires, the net electric field at a point between them is the vector sum of the individual fields. The fields due to opposite charges act in opposite directions.

---

32. (a) (i) You are given three circuit elements X, Y, and Z. They are connected one by one across a given ac source. It is found that V and I are in phase for element X. V leads I by $\frac{\pi}{4}$ for element Y while I leads V by $\frac{\pi}{4}$ for element Z. Identify elements X, Y, and Z.

Solution: Step 1: For element X, voltage and current are in phase, which means that the impedance is purely resistive. Therefore, X must be a resistor.

Step 2: For element Y, V leads I by $\frac{\pi}{4}$. This suggests that element Y behaves like an inductor, because in an inductor, the current lags the voltage, and at high frequencies, the phase difference between voltage and current increases, but here we are given that voltage leads current, which is a characteristic of inductive reactance at a specific frequency.

Step 3: For element Z, I leads V by $\frac{\pi}{4}$, which indicates capacitive behavior, because in a capacitor, current leads voltage by $\frac{\pi}{2}$ at high frequencies, and at lower frequencies, this phase difference decreases.

Conclusion:

- X is a resistor,
- Y is an inductor,
- Z is a capacitor.

Quick Tip

- In an AC circuit:

- For a resistor, voltage and current are in phase.

- For an inductor, current lags voltage, and at certain frequencies, voltage leads current.

- For a capacitor, current leads voltage.

---

32. (ii) Establish the expression for impedance of the circuit when elements X, Y, and Z are connected in series to an AC source. Show the variation of current in the circuit with the frequency of the applied AC source.

Solution:

The three elements X, Y, and Z are connected in series across an AC source. From the previous question, we know: - Element X is a resistor, with impedance $Z_X = R$. - Element Y is an inductor, with impedance $Z_Y = j\omega L$, where $\omega = 2\pi f$ is the angular frequency and L is the inductance. - Element Z is a capacitor, with impedance $Z_Z = \frac{1}{j\omega C}$, where C is the capacitance.

The total impedance Z_{total} of the series circuit is the sum of the individual impedances:

$$Z_{\text{total}} = Z_X + Z_Y + Z_Z$$

$$Z_{\text{total}} = R + j\omega L + \frac{1}{j\omega C}$$

$$Z_{\text{total}} = R + j\left(\omega L - \frac{1}{\omega C}\right)$$

Thus, the impedance of the series circuit is:

$$Z_{\text{total}} = R + j\left(\omega L - \frac{1}{\omega C}\right)$$

Step 1: Variation of current with frequency The current I in the series circuit is given by Ohm's law:

$$I = \frac{V}{Z_{\text{total}}}$$

Since Z_{total} depends on the frequency f, the current will vary with f.

- When f is low, the capacitive reactance $\left(\frac{1}{\omega C}\right)$ is high, so the current is lower. - When f increases, the inductive reactance (ωL) increases, and the capacitive reactance decreases, so the current starts increasing until it reaches a peak. - Beyond a certain frequency, the inductive reactance dominates, and the current decreases.

Thus, the current shows a resonant behavior with frequency, with the impedance being lowest at a certain resonant frequency f_0.

Correct Answer: - Impedance of the series circuit:

$$Z_{\text{total}} = R + j\left(\omega L - \frac{1}{\omega C}\right)$$

Quick Tip

The current in a series R-L-C circuit varies with frequency due to the combination of resistive, inductive, and capacitive reactances. At resonance, the impedance is minimum, and the current is maximum.

---

32. (a)(iii) In a series LCR circuit, establish the conditions under which:

(i) impedance is minimum and

(ii) wattless current flows in the circuit.

Solution:

(i) Impedance is minimum:

The total impedance Z_{total} of a series LCR circuit is given by:

$$Z_{\text{total}} = \sqrt{R^2 + (X_C - X_L)^2}$$

where:

R is the resistance,

$X_C = \frac{1}{\omega C}$ is the capacitive reactance,

$X_L = \omega L$ is the inductive reactance,

$\omega = 2\pi f$ is the angular frequency.

For impedance to be minimum, the capacitive reactance X_C and inductive reactance X_L must cancel each other out. This occurs when:

$$X_C = X_L$$

Thus, the condition for minimum impedance is when:

$$\frac{1}{\omega C} = \omega L \quad \Rightarrow \quad \omega^2 = \frac{1}{LC}$$

or

$$\omega = \frac{1}{\sqrt{LC}}$$

At this frequency, the impedance becomes:

$$Z_{\text{total}} = R$$

Hence, the impedance is minimum at the resonant frequency $f_0 = \frac{1}{2\pi\sqrt{LC}}$.

(ii) Wattless current flows in the circuit:

For wattless current, the power consumed in the AC circuit is zero. The average power P in an AC circuit over a cycle is given by:

$$P = VI\cos\phi$$

where ϕ is the phase difference between the voltage and current. For wattless current, $P = 0$, which occurs when:

$$\cos\phi = 0$$

Since $V \neq 0$ and $I \neq 0$, we must have:

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

Thus, wattless current flows when the phase difference between the voltage and current is $\frac{\pi}{2}$, which happens at resonance when $X_C = X_L$.

Correct Answer:

For impedance to be minimum: $X_C = X_L$.

For wattless current to flow: $\phi = \frac{\pi}{2}$, which occurs at resonance.

Quick Tip

- Impedance is minimum when the inductive and capacitive reactances cancel each other out at resonance. - Wattless current flows when the phase difference between voltage and current is $\frac{\pi}{2}$, which happens at resonance.

32. (b) (i) Describe the construction and working of a transformer and hence obtain the relation for $\frac{V_s}{V_p}$ in terms of the number of turns of primary and secondary.

Solution: Step 1: Construction of a Transformer:

A transformer consists of two coils, the primary coil and the secondary coil, wound on a common iron core. The core is usually made of soft iron to provide a low reluctance path for the magnetic flux. The primary coil is connected to the AC supply, and the secondary coil provides the output voltage.

Step 2: Working of a Transformer:

When an alternating current (AC) is passed through the primary coil, it generates an alternating magnetic flux. This flux passes through the iron core and induces an alternating voltage in the secondary coil through electromagnetic induction. The voltage induced in the secondary coil depends on the number of turns in the primary and secondary coils.

Step 3: Derivation of the Relation for Voltage:

According to Faraday's law of electromagnetic induction, the induced emf (electromotive force) in a coil is proportional to the rate of change of magnetic flux linkage. Thus, for the primary coil, the induced emf is:

$$V_p = N_p \frac{d\Phi}{dt}$$

where N_p is the number of turns in the primary coil and Φ is the magnetic flux.

Similarly, for the secondary coil:

$$V_s = N_s \frac{d\Phi}{dt}$$

where N_s is the number of turns in the secondary coil.

Since the rate of change of magnetic flux linkage is the same in both coils, we can equate the expressions for V_p and V_s:

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

Thus, the ratio of the voltages in the secondary and primary coils is equal to the ratio of the number of turns in the secondary and primary coils.

Conclusion:

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

Quick Tip

The voltage ratio in a transformer is directly proportional to the ratio of the number of turns in the secondary and primary coils. This relationship allows the transformer to step up or step down voltage.

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32. (b) (ii) Discuss four main causes of energy loss in a real transformer.

Solution: Step 1: Hysteresis Loss:

Hysteresis loss occurs due to the magnetization and demagnetization of the iron core. Every time the magnetic flux changes direction, energy is lost due to the lag between the magnetic field and the magnetization of the core material. This loss is proportional to the frequency of the AC supply and the volume of the core.

Step 2: Eddy Current Loss:

Eddy currents are circulating currents induced in the core of the transformer due to the alternating magnetic flux. These currents lead to energy dissipation in the form of heat. To reduce eddy current loss, the core is made of laminated sheets of iron with insulation between them.

Step 3: Resistive (Copper) Loss:

Resistive loss occurs in the windings of the transformer due to the resistance of the copper wire. As current flows through the windings, heat is generated due to the resistance of the wire. This loss increases with the square of the current and is a function of the wire's resistance.

Step 4: Leakage Flux Loss: Not all of the magnetic flux generated by the primary coil links with the secondary coil. Some of the flux leaks out of the core and does not contribute to the induction of voltage in the secondary coil. This leakage flux leads to inefficiencies and losses in the transformer.

Conclusion:

The main causes of energy loss in a real transformer are:

1. Hysteresis loss due to magnetization of the core material.
2. Eddy current loss due to circulating currents in the core.
3. Resistive (copper) loss in the windings.
4. Leakage flux loss due to non-ideal magnetic coupling between primary and secondary coils.

Quick Tip

To minimize energy loss in transformers, high-quality core materials with low hysteresis, laminated cores to reduce eddy currents, and low-resistance wires are used.

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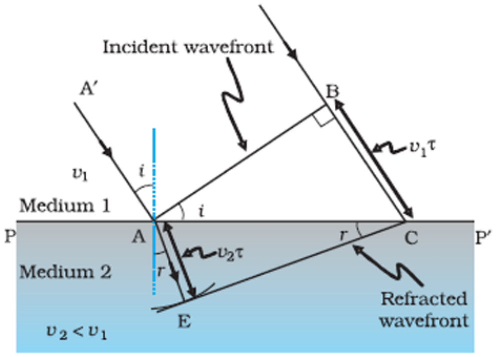
33. (a) (i) A plane light wave propagating from a rarer into a denser medium, is incident at an angle i on the surface separating two media. Using Huygen's principle, draw the refracted wave and hence verify Snell's law of refraction.

Solution:



Step 1: According to Huygen's principle, each point on a wavefront serves as a source of secondary wavelets that propagate in the forward direction. The position of the new wavefront at any later time is the envelope of these secondary wavelets.

Step 2: When a plane light wave passes from a rarer medium (with refractive index n_1) into a denser medium (with refractive index n_2), the wavefronts bend towards the normal due to a change in the speed of light. Let the angle of incidence be i and the angle of refraction be r.

Step 3: To verify Snell's law using Huygen's principle, consider the following steps:

The wavefronts in the rarer medium will have a velocity v_1, and the secondary wavelets will move slower in the denser medium with velocity v_2.

The refracted wavefront is drawn by connecting the positions of the secondary wavelets in the denser medium.

The refracted angle r is such that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant and equals the ratio of the velocities in the two media:

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

Thus, Snell's law is verified, which states that the ratio of the sines of the angles of incidence and refraction is equal to the ratio of the velocities (or the inverse of the refractive indices) in the two media.

Conclusion:

The relation derived from Huygen's principle leads to the verification of Snell's law.

Quick Tip

Huygen's principle is a useful tool to explain refraction by considering each point on a wavefront as a source of secondary wavelets. Snell's law can be derived from this principle by considering the change in the speed of light when moving between media of different refractive indices.

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33. (a) (ii) In a Young's double slit experiment, the slits are separated by 0.30 mm and the screen is kept 1.5 m away. The wavelength of light used is 600 nm. Calculate the distance between the central bright fringe and the 4th dark fringe.

Solution: Young's Double-Slit Experiment

Given

- Slit separation, $d = 0.30\,\text{mm} = 0.30 \times 10^{-3}\,\text{m}$
- Distance to the screen, $D = 1.5\,\text{m}$
- Wavelength of light, $\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$
- We are interested in the 4th dark fringe.

Position of Dark Fringes

The position of the n-th dark fringe is given by:

$$y_n = \left(n - \frac{1}{2}\right) \frac{\lambda D}{d}$$

For the 4th Dark Fringe ($n = 4$)

$$y_4 = \left(4 - \frac{1}{2}\right) \frac{\lambda D}{d} = (3.5) \frac{\lambda D}{d}$$

Substitute the Given Values

$$y_4 = 3.5 \times \frac{600 \times 10^{-9} \times 1.5}{0.30 \times 10^{-3}}$$

Calculate the Distance

$$y_4 = 3.5 \times \frac{900 \times 10^{-9}}{0.30 \times 10^{-3}} = 3.5 \times 3 \times 10^{-3} = 10.5 \times 10^{-3}\,\text{m}$$

$$y_4 = 10.5\,\text{mm}$$

Final Answer

The distance between the central bright fringe and the 4th dark fringe is:

$$\boxed{10.5\,\text{mm}}$$

Quick Tip

In a Young's double slit experiment, the distance between dark fringes is determined by the wavelength, the distance between the slits, and the screen distance. Use the formula $y = \frac{n\lambda D}{d}$ to calculate the fringe positions.

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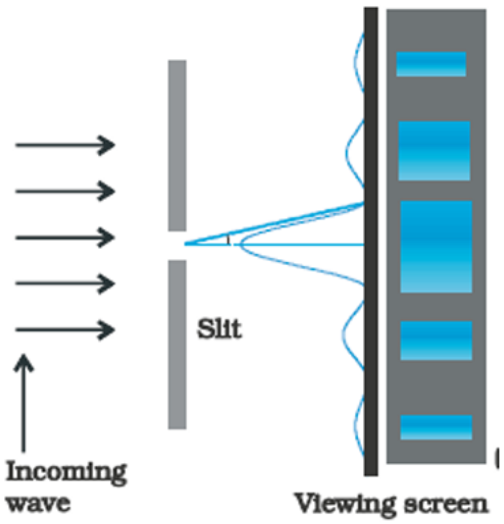
33. (b) (i) Discuss briefly diffraction of light from a single slit and draw the shape of the diffraction pattern.

Solution:



Step 1: Diffraction is the bending of light around the edges of an obstacle or aperture. It occurs when light passes through a narrow slit or around an object and spreads out. Diffraction is most noticeable when the size of the slit is comparable to the wavelength of light.

Step 2: When monochromatic light passes through a single slit, it creates a pattern on a screen. The pattern consists of a central bright fringe, with alternating dark and bright fringes on either side. The central maximum is the brightest and widest, with subsequent maxima and minima decreasing in intensity.

Step 3: The angular position of the minima in the diffraction pattern is given by the condition:

$$a \sin\theta = n\lambda \quad \text{for} \quad n = 1, 2, 3, \dots$$

where:

- a is the width of the slit,
- θ is the angle of diffraction,
- λ is the wavelength of the light,
- n is the order of the minima.

Step 4: The diffraction pattern consists of a central maximum, with minima at $\theta = \pm \sin^{-1}\left(\frac{n\lambda}{a}\right)$, and smaller maxima between the minima.

Conclusion:

The diffraction pattern for light passing through a single slit has a central bright fringe with progressively weaker bright fringes on either side, separated by dark minima.

Quick Tip

In a single-slit diffraction pattern, the central maximum is the brightest, and the intensity decreases as we move to higher-order maxima. The angular position of minima can be found using the formula $a \sin\theta = n\lambda$.

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33. (b) (ii) An object is placed between the pole and the focus of a concave mirror. Using mirror formula, prove mathematically that it produces a virtual and enlarged image.

Solution: The mirror formula is given by:

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

where:

f is the focal length of the mirror,

v is the image distance,

u is the object distance.

Let the object be placed between the pole and the focus. So, $u < f$.

Now, we rearrange the mirror formula:

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

Using the new Cartesian sign convention, we get:

$$v = \frac{(-u)(-f)}{-u - (-f)} = \frac{uf}{f - u}$$

Since $u < f$, the denominator is positive, and v will be positive, indicating that the image is virtual.

The magnification m is given by:

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

Since $m > 1$, the image is enlarged.

Thus, the image is virtual and enlarged.

Quick Tip

For a concave mirror, if the object is placed between the pole and the focus, the image formed is virtual, upright, and enlarged. The magnification is greater than 1.