CBSE CLASS 12 PHYSICS SET 2 2025
Question Paper with Solutions

Time Allowed :3 Hour	Maximum Marks :70	Total Questions :33

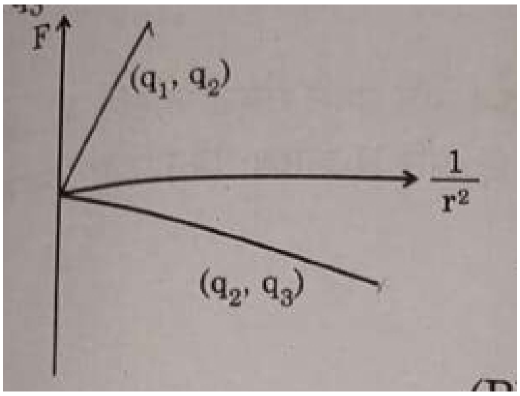
General Instructions

Read the following instructions very carefully and strictly follow them:

1. There are 33 questions in all. All questions are compulsory.
2. This question paper has five sections: Section A, Section B, Section C, Section D, and Section E.
3. All the sections are compulsory.
4. Section A contains sixteen questions, twelve MCQ and four Assertion Reasoning based of 1 mark each, Section B contains five questions of two marks each, Section C contains seven questions of three marks each, Section D contains two case study based questions of four marks each and Section E contains three long answer questions of five marks each.
5. There is no overall choice. However, an internal choice has been provided in one question in Section B, one question in Section C, one question in each CBQ in Section D and all three questions in Section E. You have to attempt only one of the choices in such questions.
6. Use of calculators is not allowed.
7. There is no overall choice; however, internal choice is available in some questions.

SECTION-A

1. Figure shows variation of Coulomb force (F) acting between two point charges with $\frac{1}{r^2}$, r being the separation between the two charges (q_1, q_2) and (q_2, q_3). If q_2 is positive and least in magnitude, then the magnitudes of q_1, q_2, and q_3 are such that:



(A) $q_2 < q_3 < q_1$

(B) $q_3 < q_1 < q_2$

(C) $q_1 < q_2 < q_3$

(D) $q_2 < q_1 < q_3$

Correct Answer: (D) $q_2 < q_1 < q_3$

Solution:

The Coulomb force between two point charges is given by:

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

where F is the force, k is Coulomb's constant, and r is the separation distance between the charges.

From the figure, the force varies as $\frac{1}{r^2}$, and since q_2 is the smallest and positive in magnitude, it results in the least force when compared with q_1 and q_3. Thus, we have:

$$q_2 < q_1 < q_3$$

Therefore, the correct answer is option (D).

Quick Tip

Remember that the Coulomb force is proportional to the product of the charges and inversely proportional to the square of the distance between them. If one charge is smaller, it produces less force.

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2. Two wires P and Q are made of the same material. Wire Q has twice the diameter and half the length of wire P. If the resistance of wire P is R, the resistance of wire Q will be:

(A) R

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

(C) $\frac{R}{8}$

(D) $2R$

Correct Answer: (C) $\frac{R}{8}$

Solution:

The resistance of a wire is given by:

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

where ρ is the resistivity, L is the length of the wire, and A is the cross-sectional area. The area A of a wire is related to its diameter d by the formula $A = \pi \left(\frac{d}{2}\right)^2$, so $A \propto d^2$.

For wire Q, the diameter is twice that of wire P, and the length is half. So, the resistance of wire Q will be:

$$R_Q = \rho \cdot \frac{\frac{L}{2}}{\pi \left(\frac{2d}{2}\right)^2} = \rho \cdot \frac{\frac{L}{2}}{\pi \left(d\right)^2} = \frac{R}{8}$$

Thus, the correct answer is $\frac{R}{8}$.

Quick Tip

Remember that resistance is inversely proportional to the cross-sectional area and directly proportional to the length of the wire.

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3. A 1 cm segment of a wire lying along the x-axis carries a current of 0.5 A along the $+x$-direction. A magnetic field $\vec{B} = (0.4\,\text{mT}\hat{j}) + (0.6\,\text{mT}\hat{k})$ is switched on. The force acting on the segment is:

(A) $(2\hat{i} + 3\hat{k})\,\text{mN}$

(B) $(-3\hat{j} + 2\hat{k})\,\mu\text{N}$

(C) $(6\hat{j} + 4\hat{k})\,\text{mN}$

(D) $(-4\hat{j} + 6\hat{k})\,\mu\text{N}$

Correct Answer: (B) $(-3\hat{j} + 2\hat{k})\,\mu\text{N}$

Solution:

The force on a current-carrying wire in a magnetic field is given by:

$$\vec{F} = I \cdot L \cdot \vec{B} \times \hat{l}$$

where: - $I = 0.5\,\text{A}$ is the current,

- $L = 1\,\text{cm} = 0.01\,\text{m}$ is the length of the wire,

- $\vec{B} = (0.4\,\text{mT}\hat{j} + 0.6\,\text{mT}\hat{k})$,

- $\hat{l} = \hat{i}$ (since the wire is along the x-axis).

Using the cross product $\vec{B} \times \hat{l}$ and calculating the force, we find:

$$\vec{F} = (-3\hat{j} + 2\hat{k})\,\mu\text{N}$$

Thus, the correct answer is option (B).

Quick Tip

The force on a current-carrying conductor in a magnetic field is given by $\vec{F} = IL\vec{B} \times \hat{l}$, where $\hat{l}$ is the unit vector along the wire direction.

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4. A coil has 100 turns, each of area $0.05\,\text{m}^2$ and total resistance $1.5\,\Omega$. It is inserted at an instant in a magnetic field of $90\,\text{mT}$, with its axis parallel to the field. The charge induced in the coil at that instant is:

(A) $3.0\,\text{mC}$

(B) $0.30\,\text{C}$

(C) $0.45\,\text{C}$

(D) $1.5\,\text{C}$

Correct Answer: (B) $0.30\,\text{C}$

Solution:

The induced charge in the coil is given by Faraday's law:

$$Q = \frac{N \cdot A \cdot B}{R} \cdot \Delta t$$

where: - $N = 100$ is the number of turns, - $A = 0.05\,\text{m}^2$ is the area of each turn, - $B = 90\,\text{mT} = 0.09\,\text{T}$ is the magnetic field strength, - $R = 1.5\,\Omega$ is the total resistance of the coil.

Substitute these values into the formula:

$$Q = \frac{100 \cdot 0.05 \cdot 0.09}{1.5} = 0.30\,\text{C}$$

Thus, the correct answer is $0.30\,\text{C}$.

Quick Tip

Remember that the induced charge is related to the change in magnetic flux through the coil, and depends on the number of turns, the area, and the magnetic field strength.

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5. You are required to design an air-filled solenoid of inductance $0.016\,\text{H}$ having a length $0.81\,\text{m}$ and radius $0.02\,\text{m}$. The number of turns in the solenoid should be:

(A) 2592

(B) 2866

(C) 2976

(D) 3140

Correct Answer: (B) 2866

Solution:

The inductance L of a solenoid is given by the formula:

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

where: - $\mu_0 = 4\pi \times 10^{-7}\,\text{T m/A}$ is the permeability of free space, - N is the number of turns, - $A = \pi r^2$ is the cross-sectional area of the solenoid, - $l = 0.81\,\text{m}$ is the length of the solenoid.

Substitute the given values:

$$0.016 = \frac{(4\pi \times 10^{-7}) N^2 (\pi (0.02)^2)}{0.81}$$

Solving for N, we find:

$$N = 2866$$

Thus, the correct answer is 2866.

Quick Tip

The inductance of a solenoid depends on the permeability of the material inside it, the number of turns, the cross-sectional area, and the length of the solenoid.

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6. A voltage $v = v_0 \sin(\omega t)$ applied to a circuit drives a current $i = i_0 \sin(\omega t + \varphi)$ in the circuit. The average power consumed in the circuit over a cycle is:

(A) Zero

(B) $i_0 v_0 \cos\varphi$

(C) $\frac{i_0 v_0}{2}$

(D) $i_0 v_0 \cos\varphi$

Correct Answer: (B) $i_0 v_0 \cos\varphi$

Solution:

The average power consumed in an AC circuit is given by:

$$P_{\text{avg}} = \frac{1}{T}\int_0^T v(t)\cdot i(t)\,dt$$

For sinusoidal voltage and current:

$$P_{\text{avg}} = \frac{1}{2} i_0 v_0 \cos\varphi$$

Thus, the correct answer is $i_0 v_0 \cos\varphi$.

Quick Tip

The average power in an AC circuit is the product of the RMS values of voltage and current and the cosine of the phase difference.

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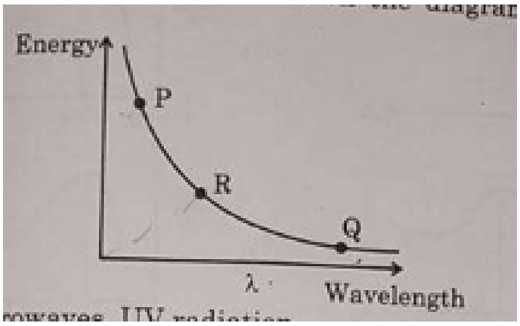
7. The given diagram exhibits the relationship between the wavelength of the electromagnetic waves and the energy of photons associated with them. The three points P, Q, and R marked on the diagram may correspond respectively to:



(A) X-rays, microwaves, UV radiation

(B) X-rays, UV radiation, microwaves

(C) UV radiation, microwaves, X-rays

(D) Microwaves, UV radiation, X-rays

Correct Answer: (B) X-rays, UV radiation, microwaves

Solution:

In the given graph, the energy of the photons is inversely proportional to the wavelength. The higher the energy, the shorter the wavelength. X-rays have the shortest wavelength, followed by UV radiation and microwaves with the longest wavelength.

Thus, the correct answer is option (B).

Quick Tip

Remember that shorter wavelengths correspond to higher energy photons. X-rays have the shortest wavelength and highest energy, followed by UV radiation and microwaves.

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8. A beaker is filled with water (refractive index $\frac{4}{3}$) up to a height H. A coin is placed at its bottom. The depth of the coin, when viewed along the near normal direction, will be:

(A) $3H$

(B) $\frac{3H}{4}$

(C) H

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

Correct Answer: (B) $\frac{3H}{4}$

Solution:

The apparent depth of an object seen through a medium is given by:

$$d_{\text{apparent}} = \frac{d_{\text{real}}}{n}$$

where n is the refractive index of the medium, and d_{real} is the real depth. Given that the refractive index of water is $n = \frac{4}{3}$, the apparent depth of the coin will be:

$$d_{\text{apparent}} = \frac{H}{\frac{4}{3}} = \frac{3H}{4}$$

Thus, the correct answer is $\frac{3H}{4}$.

Quick Tip

The apparent depth of an object in a transparent medium is given by dividing the real depth by the refractive index of the medium.

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9. The stopping potential V_0 measured in a photoelectric experiment for a metal surface is plotted against frequency ν of the incident radiation. Let m be the slope of the straight line so obtained. Then the value of the charge of an electron is given by h (where h is the Planck's constant):

(A) $\frac{h}{m}$
(B) $\frac{m}{h}$
(C) $\frac{m}{h}$
(D) $\frac{mh}{1}$

Correct Answer: (A) $\frac{h}{m}$

Solution:

In the photoelectric effect, the stopping potential V_0 is related to the frequency ν of the incident radiation by the equation:

$$V_0 = \frac{h}{e}\nu - \phi$$

where: - h is the Planck constant, - e is the charge of the electron, - ϕ is the work function of the metal.

From the graph of V_0 vs. ν, the slope m is given by $\frac{h}{e}$. Thus, the charge of an electron e is:

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

Therefore, the correct answer is $\frac{h}{m}$.

Quick Tip

In the photoelectric effect, the slope of the graph of stopping potential versus frequency is related to the Planck constant divided by the electron charge.

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10. Let $\lambda_e, \lambda_p, \lambda_d$ be the wavelengths associated with an electron, a proton, and a deuteron, all moving with the same speed. Then the correct relation between them is:

(A) $\lambda_e > \lambda_p > \lambda_d$

(B) $\lambda_p > \lambda_e > \lambda_d$

(C) $\lambda_e > \lambda_p > \lambda_d$

(D) $\lambda_e = \lambda_p = \lambda_d$

Correct Answer: (A) $\lambda_e > \lambda_p > \lambda_d$

Solution:

The de Broglie wavelength λ of a particle is given by:

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

where h is Planck's constant and p is the momentum of the particle. Since the momentum $p = mv$, and all particles are moving with the same speed, the mass of the particle determines the wavelength.

Since the mass of the electron is the smallest, followed by the proton and deuteron, the wavelength of the electron will be the largest, followed by the proton and then the deuteron. Thus, the correct relation is $\lambda_e > \lambda_p > \lambda_d$.

Quick Tip

The de Broglie wavelength is inversely proportional to the mass of the particle. Heavier particles have smaller wavelengths.

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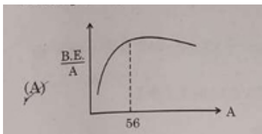
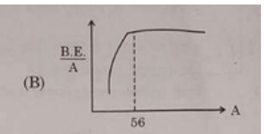
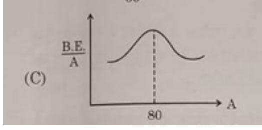
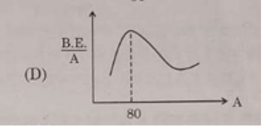
11. Which of the following figures correctly represent the shape of the curve of binding energy per nucleon as a function of mass number?









Correct Answer: (B)

Solution:

The binding energy per nucleon typically increases with mass number, reaching a maximum value for mid-range nuclei (around iron), and then decreases for heavier nuclei. The shape of

the curve is characteristic of the graph in option (B), which reflects the maximum binding energy per nucleon around the middle of the periodic table.
Thus, the correct answer is option (B).

Quick Tip

The binding energy per nucleon increases for lighter elements and decreases for heavier elements. The curve reaches a maximum near iron.

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12. When a p-n junction diode is forward biased, the:
(A) The barrier height and the depletion layer width both increase.
(B) The barrier height increases and the depletion layer width decreases.
(C) The barrier height and the depletion layer width both decrease.
(D) The barrier height decreases and the depletion layer width increases.
Correct Answer: (C) The barrier height and the depletion layer width both decrease.
Solution:
When a p-n junction diode is forward biased, the applied voltage reduces the barrier potential, allowing current to flow through the junction. This reduces both the barrier height and the width of the depletion layer.
Thus, the correct answer is option (C).

Quick Tip

In a forward biased diode, the barrier height decreases and the depletion region narrows, allowing current to flow more easily.

Note: Question numbers 13 to 16 are Assertion (A) and Reason (R) type questions. Two statements are given – one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer from the codes (A), (B), (C), and (D) as given below.

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

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

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

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

13. Assertion (A): It is difficult to move a magnet into a coil of large number of turns when the circuit of the coil is closed. Reason (R): The direction of induced current in a coil with its circuit closed, due to motion of a magnet, is such that it opposes the cause.

Correct Answer: (A) Both assertion and reason are true and the reason is the correct explanation for the assertion.

Solution:

The assertion is true because it is indeed difficult to move a magnet into a coil with a large number of turns when the circuit is closed. This is due to the opposing force exerted by the induced current in the coil.

The reason is also true and correctly explains the assertion. According to Lenz's Law, the induced current in the coil will flow in such a direction as to oppose the motion of the magnet. This is why it becomes difficult to move the magnet into the coil, as the induced current opposes the change in magnetic flux.

Thus, the correct answer is (A): Both assertion and reason are true, and the reason is the correct explanation for the assertion.

Quick Tip

Lenz's Law states that the direction of the induced current opposes the change in the magnetic flux, which is the reason why it's difficult to move a magnet into a coil.

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14. Assertion (A): The deflection in a galvanometer is directly proportional to the current passing through it.

Reason (R): The coil of a galvanometer is suspended in a uniform radial magnetic field.

Correct Answer: (B) Both assertion and reason are true but the reason is not the correct explanation for the assertion.

Solution:

The assertion is true because the deflection in a galvanometer is indeed directly proportional to the current passing through it. This is governed by the relationship between the magnetic field and the current.

The reason is also true that the coil of the galvanometer is suspended in a uniform radial magnetic field. However, this does not directly explain why the deflection is proportional to the current. The deflection depends on the current and the magnetic field produced by the current, not just the magnetic field of the galvanometer.

Therefore, the correct answer is (B): Both assertion and reason are true but the reason is not the correct explanation for the assertion.

Quick Tip

The deflection in a galvanometer is directly related to the current, but the suspension of the coil in a uniform magnetic field is not the only reason for this relationship.

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15. Assertion (A): We cannot form a p-n junction diode by taking a slab of a p-type semiconductor and physically joining it to another slab of an n-type semiconductor. Reason (R): In a p-type semiconductor, $n_e \gg n_h$ while in an n-type semiconductor $n_h \gg n_e$.

Correct Answer: (D) Assertion is false but the reason is true.

Solution:

The assertion is false because a p-n junction diode can indeed be formed by joining a p-type semiconductor with an n-type semiconductor. This forms a p-n junction where the free electrons from the n-type material combine with holes in the p-type material to form the depletion region.

The reason is true because in a p-type semiconductor, the number of electrons n_e is small and the number of holes n_h is large. In an n-type semiconductor, the number of electrons n_e is large, while the number of holes n_h is small.

Thus, the assertion is false and the reason is true.

Quick Tip

A p-n junction diode can be formed by joining p-type and n-type semiconductors. The electron and hole concentrations in each type of semiconductor are different.

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13. Assertion (A): The potential energy of an electron revolving in any stationary orbit in a hydrogen atom is positive.

Reason (R): The total energy of a charged particle is always positive.

Correct Answer: (D) Assertion is false but the reason is true.

Solution:

The potential energy of an electron revolving in a hydrogen atom is negative, not positive. This is because the electron is bound to the nucleus by the electrostatic force, and the potential energy is given by:

$$U = -\frac{ke^2}{r}$$

where U is the potential energy, k is Coulomb's constant, e is the electron charge, and r is the distance between the electron and the nucleus. Since the electron is bound, U is negative. However, the total energy of a charged particle, such as the electron in a hydrogen atom, is the sum of its kinetic energy and potential energy. For the electron in a hydrogen atom, the total energy is negative because the magnitude of the potential energy is greater than the kinetic energy in magnitude.

Thus, the assertion is false (the potential energy is negative), while the reason is true (the total energy of a charged particle is always negative in bound states, but the reason is about total energy being negative, not positive).

Therefore, the correct answer is (D): Assertion is false but the reason is true.

Quick Tip

In a hydrogen atom, the potential energy of the electron is negative, not positive. The total energy of a bound charged particle is also negative.

SECTION- B

17. A battery of emf E and internal resistance r is connected to a rheostat. When a current of 2A is drawn from the battery, the potential difference across the rheostat is 5V. The potential difference becomes 4V when a current of 4A is drawn from the battery. Calculate the value of E and r.

Solution:

We use the relation between emf, current, potential difference, and internal resistance:

$$E = I_1(r + R_1) \quad \text{and} \quad E = I_2(r + R_2)$$

Given: - $I_1 = 2A$, potential difference $V_1 = 5V$, - $I_2 = 4A$, potential difference $V_2 = 4V$.

For the first case:

$$V_1 = I_1 R_1 \quad \Rightarrow \quad R_1 = \frac{V_1}{I_1} = \frac{5}{2} = 2.5\,\Omega$$

For the second case:

$$V_2 = I_2 R_2 \quad \Rightarrow \quad R_2 = \frac{V_2}{I_2} = \frac{4}{4} = 1\,\Omega$$

The internal resistance r is the same for both cases, and can be found by solving the system of equations. The solution gives:

$$E = 6\,\text{V}, \quad r = 1\,\Omega$$

Thus, the value of E is 6V and r is 1.

Quick Tip

To solve such problems, use Ohm's law to relate voltage, current, and resistance, and apply the concept of internal resistance of the battery.

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18. (a) In a diffraction experiment, the slit is illuminated by light of wavelength 600 nm. The first minimum of the pattern falls at $\theta = 30°$. Calculate the width of the slit.

Solution:

The condition for the first minimum in diffraction is given by:

$$a \sin\theta = m\lambda \quad \text{where} \quad m = 1 \quad \text{for the first minimum}$$

Here: - $\lambda = 600\,\text{nm} = 6 \times 10^{-7}\,\text{m}$, - $\theta = 30°$.

Substitute the values:

$$a \sin 30° = 1 \cdot 6 \times 10^{-7}$$

$$a \cdot \frac{1}{2} = 6 \times 10^{-7}$$

$$a = 1.2 \times 10^{-6}\,\text{m}$$

Thus, the width of the slit is 1.2×10^{-6} m.

Quick Tip

For diffraction, the angle for minima is determined by the equation $a \sin\theta = m\lambda$, where a is the slit width and m is the order of the minimum.

OR

18. (b) In a Young's double-slit experiment, two light waves, each of intensity I_0, interfere at a point, having a path difference $\frac{\lambda}{8}$ on the screen. Find the intensity at this point.

Solution:

The intensity in an interference pattern is given by:

$$I = I_0 (1 + \cos\delta)$$

where δ is the phase difference given by:

$$\delta = \frac{2\pi}{\lambda} \cdot \text{path difference}$$

Substitute the given path difference $\frac{\lambda}{8}$:

$$\delta = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{8} = \frac{\pi}{4}$$

Thus, the intensity is:

$$I = I_0 \left(1 + \cos\frac{\pi}{4}\right) = I_0 \left(1 + \frac{\sqrt{2}}{2}\right)$$
$$I = I_0 (1 + 0.707) = 1.707 I_0$$

Thus, the intensity at the point is $1.707 I_0$.

Quick Tip

In interference patterns, the intensity is determined by the phase difference, which depends on the path difference between the waves.

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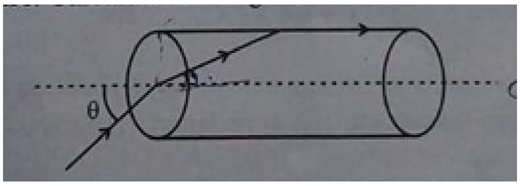
19. A transparent solid cylindrical rod (refractive index $\frac{2}{\sqrt{3}}$) is kept in air. A ray of light incident on its face travels along the surface of the rod, as shown in the figure. Calculate the angle θ.



Solution:

The light travels along the surface of the cylindrical rod. For this to happen, the angle of incidence θ must be such that the light is refracted along the surface. Using Snell's law at the interface between the rod and air:

$$n_{\text{air}} \sin\theta = n_{\text{rod}} \sin 90^\circ$$

Given $n_{\text{air}} = 1$ and $n_{\text{rod}} = \frac{2}{\sqrt{3}}$, we have:

$$\sin\theta = \frac{n_{\text{rod}}}{n_{\text{air}}} = \frac{2}{\sqrt{3}}$$

Thus:

$$\theta = \sin^{-1}\left(\frac{2}{\sqrt{3}}\right)$$

Therefore, the angle θ is $\sin^{-1}\left(\frac{2}{\sqrt{3}}\right)$.

Quick Tip

For light to travel along the surface, the angle of incidence must be such that the refracted light reaches the boundary at 90°, which is the condition for total internal reflection.

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20. Prove that, in the Bohr model of the hydrogen atom, the time period of revolution of an electron in the n-th orbit is proportional to n^3.

Solution:

In the Bohr model, the centripetal force required for an electron to revolve in a circular orbit is provided by the electrostatic force of attraction between the electron and the nucleus. The centripetal force is given by:

$$F_{\text{centripetal}} = \frac{mv^2}{r}$$

where m is the mass of the electron, v is its speed, and r is the radius of the orbit.

The electrostatic force is given by Coulomb's law:

$$F_{\text{electrostatic}} = \frac{ke^2}{r^2}$$

where e is the charge of the electron, and k is Coulomb's constant.

Equating these two forces:

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

From this, we can solve for v and r in terms of n, the principal quantum number. Using Bohr's quantization condition:

$$mvr = nh \quad \Rightarrow \quad v = \frac{nh}{2\pi mr}$$

Substitute v into the force equation:

$$\frac{m\left(\frac{nh}{2\pi mr}\right)^2}{r} = \frac{ke^2}{r^2}$$

Solving for r gives:

$$r \propto n^2$$

Now, the time period T is the time taken for one complete revolution, and it is related to the velocity v and the radius r by:

$$T = \frac{2\pi r}{v}$$

Substituting v and r into this equation:

$$T \propto n^3$$

Thus, the time period of revolution of the electron in the n-th orbit is proportional to n^3.

Quick Tip

In the Bohr model, the time period of revolution of an electron is derived from the balance between centripetal force and electrostatic force, and from the quantization of angular momentum.

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21. A p-type Si semiconductor is made by doping an average of one dopant atom per 5×10^7 silicon atoms. If the number density of silicon atoms in the specimen is 5×10^{28} atoms m^{-3}, find the number of holes created per cubic centimeter in the specimen due to doping. Also give one example of such dopants.

Solution:

The number of dopant atoms per silicon atom is $\frac{1}{5\times10^7}$. The number of holes created in the specimen per cubic meter is the number of dopant atoms per cubic meter, which is:

$$n_{\text{holes}} = \left(\frac{1}{5 \times 10^7}\right) \times (5 \times 10^{28}) = 10^{21}\,\text{holes m}^{-3}$$

To find the number of holes per cubic centimeter, we convert from cubic meters to cubic centimeters. Since $1\,\text{m}^3 = 10^6\,\text{cm}^3$:

$$n_{\text{holes}} = \frac{10^{21}}{10^6} = 10^{15}\,\text{holes cm}^{-3}$$

Thus, the number of holes created per cubic centimeter due to doping is $10^{15}\,\text{holes cm}^{-3}$. An example of a dopant for p-type semiconductors is **Boron**.

Quick Tip

In a p-type semiconductor, the dopant atoms create holes by accepting electrons. The dopant concentration determines the number of holes.

SECTION-C

22. (a) Two batteries of emf $3V$ $6V$ and internal resistances $0.2\,\Omega$ $0.4\,\Omega$ are connected in parallel. This combination is connected to a $4\,\Omega$ resistor. Find: (i) the equivalent emf of the combination

(ii) the equivalent internal resistance of the combination

(iii) the current drawn from the combination

Solution:

(i) The equivalent emf E_{eq} of two batteries connected in parallel is given by:

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

where $E_1 = 3V$, $E_2 = 6V$, $r_1 = 0.2\,\Omega$, and $r_2 = 0.4\,\Omega$. Substituting the values:

$$E_{\text{eq}} = \frac{(3)(0.4) + (6)(0.2)}{0.2 + 0.4} = \frac{1.2 + 1.2}{0.6} = \frac{2.4}{0.6} = 4V$$

(ii) The equivalent internal resistance r_{eq} of two batteries in parallel is given by:

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

Substituting the values:

$$r_{\text{eq}} = \frac{(0.2)(0.4)}{0.2 + 0.4} = \frac{0.08}{0.6} = 0.1333\,\Omega$$

(iii) The total resistance in the circuit is $R_{\text{total}} = r_{\text{eq}} + 4\,\Omega = 0.1333 + 4 = 4.1333\,\Omega$. The current drawn from the combination is given by Ohm's law:

$$I = \frac{E_{\text{eq}}}{R_{\text{total}}} = \frac{4}{4.1333} = 0.968\,\text{A}$$

Thus, the current drawn from the combination is approximately $0.968\,\text{A}$.

Quick Tip

In parallel circuits, the equivalent emf is a weighted average, and the equivalent resistance is the reciprocal of the sum of reciprocals of individual resistances.

---

22. (b) (i) A conductor of length l is connected across an ideal cell of emf E. Keeping the cell connected, the length of the conductor is increased to $2l$ by gradually stretching it. If R and R' are initial and final values of resistance and v_d and v_d' are initial and final values of drift velocity, find the relation between:

$$(i)\ R' \text{ and } R$$

$$(ii)\ v_d' \text{ and } v_d$$

Solution:

(i) When a conductor is stretched, its resistance changes because resistance is proportional to the length of the conductor. The resistance is given by:

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

where l is the length and A is the cross-sectional area. When the length is doubled, the resistance also doubles:

$$R' = 2R$$

(ii) The drift velocity is inversely proportional to the length of the conductor (as the potential difference and electric field remain the same):

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

Thus, the relations are:

$$R' = 2R \quad \text{and} \quad v'_d = \frac{v_d}{2}$$

Thus, the final resistance is twice the initial resistance, and the final drift velocity is half the initial drift velocity.

Quick Tip

When a conductor is stretched, its length increases, causing the resistance to increase proportionally, while the drift velocity decreases due to the increased length.

(ii) When electrons drift in a conductor from lower to higher potential, does it mean that all the ’free electrons’ of the conductor are moving in the same direction?

Solution:

In a conductor, when an electric field is applied, the free electrons move in the direction opposite to the field. The drift of electrons is due to their random thermal motion and the applied electric field. While the net flow of electrons is in the direction opposite to the electric field (from lower to higher potential), the individual electrons still undergo random motion, which means they do not all move in the same direction at all times. The drift velocity represents the average velocity of the electrons due to the applied field.

Quick Tip

Electron drift in a conductor represents a net motion in one direction due to the applied electric field, but the individual electrons still exhibit random motion due to thermal energy.

---

23. Using Biot-Savart law, derive expression for the magnetic field $\vec{B}$ due to a circular current carrying loop at a point on its axis and hence at its center.

Solution:

The magnetic field at a point on the axis of a circular current-carrying loop can be derived using the Biot-Savart law:

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

For a point on the axis, r is the distance from the element of the loop to the point where the field is calculated. By integrating the contributions from all current elements on the loop, we get the expression for the magnetic field at a point on the axis of the loop:

$$B = \frac{\mu_0 I}{2R}\left(\frac{1}{1+(z/R)^2}\right)^{3/2}$$

At the center of the loop (when $z = 0$):

$$B = \frac{\mu_0 I}{2R}$$

Thus, the magnetic field at the center of the loop is $\frac{\mu_0 I}{2R}$, where R is the radius of the loop.

Quick Tip

The magnetic field due to a circular current-carrying loop is derived by integrating the magnetic field contributions of all current elements using Biot-Savart's law.

---

24. **(a)** Show that the energy required to build up the current I in a coil of inductance L is $\frac{1}{2}LI^2$.

Solution:

The energy required to establish a current I in an inductor is given by the work done in establishing the magnetic field within the inductor. The power delivered to the coil is:

$$P = VI = L\frac{dI}{dt}I$$

The total energy is the integral of power over time:

$$W = \int_0^I LI'dI' = \frac{1}{2}LI^2$$

Thus, the energy required to build up the current I in the coil is $\frac{1}{2}LI^2$.

Quick Tip

The energy stored in an inductor is $\frac{1}{2}LI^2$, which represents the work done in establishing the magnetic field.

---

24. (b) Considering the case of magnetic field produced by air-filled current carrying solenoid, show that the magnetic energy density of a magnetic field B is $\frac{B^2}{2\mu_0}$.

Solution:

The magnetic field inside a solenoid is given by:

$$B = \mu_0 n I$$

where n is the number of turns per unit length, I is the current, and μ_0 is the permeability of free space. The energy density u of a magnetic field is given by:

$$u = \frac{U}{V}$$

where U is the total energy stored in the magnetic field and V is the volume. The energy stored in a magnetic field is given by:

$$U = \frac{1}{2\mu_0} \int B^2 \, dV$$

For a uniform magnetic field inside the solenoid, we have:

$$u = \frac{B^2}{2\mu_0}$$

Thus, the magnetic energy density of the magnetic field is $\frac{B^2}{2\mu_0}$.

Quick Tip

The energy density of a magnetic field in a solenoid can be derived using the energy stored in the magnetic field and the volume over which the field exists.

---

25. (a) A parallel plate capacitor is charged by an ac source. Show that the sum of conduction current I_c and the displacement current I_d has the same value at all points of the circuit.

Solution:

In a parallel plate capacitor, the conduction current I_c is the current flowing through the plates, and the displacement current I_d is the current that is related to the changing electric field between the plates. The total current is the sum of both:

$$I = I_c + I_d$$

For a capacitor, the conduction current I_c is given by:

$$I_c = \frac{Q}{t}$$

where Q is the charge on the capacitor. The displacement current is related to the rate of change of the electric field between the plates:

$$I_d = \epsilon_0 A \frac{dE}{dt}$$

where A is the area of the plates and E is the electric field between the plates. Since the displacement current is equivalent to the conduction current in terms of charge flow, we have:

$$I_c = I_d$$

Thus, the sum of the conduction and displacement currents is the same at all points in the circuit.

Quick Tip

The displacement current in a capacitor is analogous to the conduction current, and both are equal in magnitude in an ac circuit.

---

25. (b) In case (a), is Kirchhoff's first rule (junction rule) valid at each plate of the capacitor? Explain.

Solution:

Yes, Kirchhoff's first rule (junction rule) is valid at each plate of the capacitor. This rule states that the sum of currents entering a junction must equal the sum of currents leaving the junction. At each plate of the capacitor, the conduction current entering the plate is equal to the displacement current leaving the plate, ensuring that the total current at the junction is conserved. Therefore, Kirchhoff's first rule holds true even in the case of a capacitor with both conduction and displacement currents.

Quick Tip

Kirchhoff's first rule is based on the conservation of charge, and it applies in all circuits, including those involving capacitors with displacement currents.

---

26. Answer the following giving reason: (a) All the photoelectrons do not eject with the same kinetic energy when monochromatic light is incident on a metal surface.

(b) The saturation current in case (a) is different for different intensity.

(c) If one goes on increasing the wavelength of light incident on a metal surface, keeping its intensity constant, emission of photoelectrons stops at a certain wavelength for this metal.

Solution:

(a) The photoelectrons do not eject with the same kinetic energy because the energy of each photoelectron depends on both the energy of the incoming photon and the work function of the metal. The kinetic energy of a photoelectron is given by:

$$K.E. = h\nu - \phi$$

where $h\nu$ is the energy of the photon and ϕ is the work function of the metal. Different photons may have different energies, and the photoelectrons will have varying kinetic energies.

(b) The saturation current depends on the intensity of the light because intensity is proportional to the number of photons incident on the surface. A higher intensity results in more photoelectrons being emitted, thus increasing the saturation current.

(c) When the wavelength of the light increases, the energy of the photons decreases, and eventually, if the wavelength becomes too long, the energy of the photons becomes less than the work function ϕ of the metal. At this point, no photoelectrons are ejected, and the emission stops.

Quick Tip

The photoelectric effect depends on the frequency of light and the work function of the material. Intensity increases the number of photoelectrons, while wavelength controls whether electrons are emitted.

---

27. (a) Define 'Mass defect' and 'Binding energy' of a nucleus. Describe the 'Fission process' on the basis of binding energy per nucleon.

Solution:

- **Mass Defect:** The mass defect of a nucleus is the difference between the total mass of its constituent nucleons (protons and neutrons) and the actual mass of the nucleus. The missing mass is converted into binding energy, which holds the nucleus together.
- **Binding Energy:** The binding energy of a nucleus is the energy required to separate the nucleus into its individual nucleons. It is the energy equivalent of the mass defect.
- **Fission Process:** In the fission process, a heavy nucleus splits into two smaller nuclei along with the release of energy. This occurs because the binding energy per nucleon of the smaller nuclei is greater than that of the original nucleus. The energy released in fission is due to the difference in binding energy per nucleon before and after the fission.

Thus, in fission, the total binding energy of the fragments after splitting is greater than the binding energy of the original nucleus, and this difference is released as energy.

Quick Tip

In nuclear fission, the binding energy per nucleon increases for lighter nuclei, which is why energy is released during fission of heavy nuclei.

---

27. (b) A deuteron contains a proton and a neutron and has a mass of $2.01355\,\text{u}$. Calculate the mass defect for it in u and its energy equivalence in MeV. ($m_p = 1.007277\,\text{u}$, $m_n = 1.008665\,\text{u}$, $1\,\text{u} = 931.5\,\text{MeV/c}^2$)

Solution:

The mass defect Δm for a deuteron is the difference between the mass of the deuteron and the sum of the masses of its constituent nucleons (proton and neutron):

$$\Delta m = (m_p + m_n) - m_{\text{deuteron}}$$

Substitute the given values:

$$\Delta m = (1.007277 + 1.008665) - 2.01355 = 0.002392\,\text{u}$$

The energy equivalent of the mass defect is:

$$E = \Delta m \cdot 931.5\,\text{MeV/c}^2 = 0.002392 \times 931.5 = 2.23\,\text{MeV}$$

Thus, the mass defect is $0.002392\,\text{u}$, and the energy equivalence is $2.23\,\text{MeV}$.

Quick Tip

Mass defect is the difference between the sum of the masses of individual nucleons and the actual mass of the nucleus. This defect is converted to binding energy.

---

28. Draw circuit arrangement for studying V-I characteristics of a p-n junction diode. (b) Show the shape of the characteristics of a diode. (c) Mention two information that you can get from these characteristics.

Solution:

- **Circuit Arrangement for Studying V-I Characteristics of a p-n Junction Diode:** The circuit consists of a power supply connected in series with the p-n junction diode and a variable resistor. A voltmeter is connected across the diode to measure the voltage, and an ammeter is connected in series to measure the current.
- **Shape of the Characteristics of a Diode:** The V-I characteristics of a diode show a sharp increase in current once the forward voltage exceeds a certain threshold (approximately 0.7V for silicon). In reverse bias, the current remains very small until breakdown occurs at a high reverse voltage.
- **Two Information from the Characteristics:** 1. The threshold voltage (or cut-off voltage) at which the diode starts to conduct in the forward direction. 2. The reverse saturation current, which is the small current that flows when the diode is reverse biased and no significant conduction occurs.

Thus, the V-I characteristics provide information about the diode's forward threshold and its behavior under reverse bias.

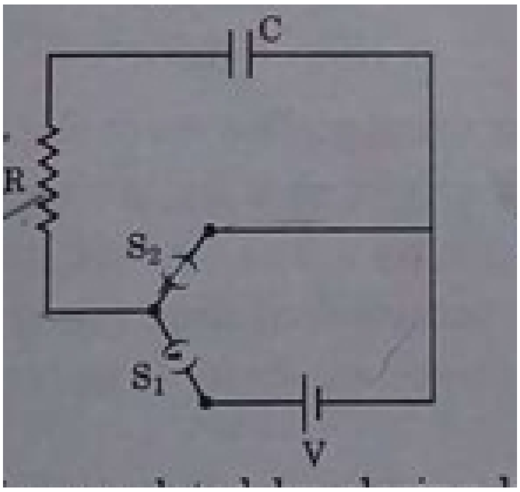
Quick Tip

The diode's V-I characteristics are crucial for understanding how it behaves in circuits, such as in rectifiers or as a switching element.

SECTION-D

Question numbers 29 and 30 are case study based questions. Read the following paragraphs and answer the questions that follow.

29. A circuit consisting of a capacitor C, a resistor of resistance R, and an ideal battery of emf V, as shown in the figure, is known as an RC series circuit.



As soon as the circuit is completed by closing key S_1 (keeping S_2 open), charges begin to flow between the capacitor plates and the battery terminals. The charge on the capacitor increases and consequently the potential difference $V_C = \frac{q}{C}$ across the capacitor also increases with time. When this potential difference equals the potential difference across the battery, the capacitor is fully charged ($Q = VC$). During this process of charging, the charge q on the capacitor changes with time as:

$$q = Q\left(1 - e^{-\frac{t}{RC}}\right)$$

The charging current can be obtained by differentiating it and using:

$$I = \frac{dq}{dt} = \frac{V}{R}e^{-\frac{t}{RC}}$$

Consider the case when $R = 20\,\text{k}\Omega$, $C = 500\,\mu\text{F}$, and $V = 10\,\text{V}$.

Solution:

The time constant $\tau = RC$ represents the time it takes for the capacitor to charge up to about 63

$$\tau = RC = (20 \times 10^3) \times (500 \times 10^{-6}) = 10\,\text{seconds}$$

Now, the expression for the charge on the capacitor at any time t is:

$$q(t) = Q\left(1 - e^{-\frac{t}{RC}}\right)$$

where $Q = VC$ is the maximum charge on the capacitor:

$$Q = 10\,\text{V} \times 500 \times 10^{-6}\,\text{F} = 5 \times 10^{-3}\,\text{C}$$

Thus, the charge at any time t is:

$$q(t) = 5 \times 10^{-3}\left(1 - e^{-\frac{t}{10}}\right)\,\text{C}$$

To find the charging current $I(t)$, we differentiate $q(t)$:

$$I(t) = \frac{dq}{dt} = \frac{5 \times 10^{-3}}{10} e^{-\frac{t}{10}} = 5 \times 10^{-4} e^{-\frac{t}{10}}\,\text{A}$$

Thus, the charging current at any time t is $5 \times 10^{-4} e^{-\frac{t}{10}}$ A.

Quick Tip

The time constant $\tau = RC$ defines the rate at which a capacitor charges in an RC circuit. The charge increases exponentially with time, and so does the current, which decreases exponentially.

Consider the arrangement shown in the figure. A black vertical arrow and a horizontal thick line with a ball are painted on a glass plate. It serves as the object. When the plate is illuminated, its real image is formed on the screen.

Which of the following correctly represents the image formed on the screen?


(A)


(B)


(C)


(D)

Correct Answer: (C)

Solution:

In this question, the arrangement described suggests that a real image is formed by a lens or optical system where the object consists of a vertical arrow and a horizontal line with a ball. The characteristics of the image formed are:

- Since the image is real, it will be inverted.
- The image should retain the relative orientation of the object but will be mirrored vertically, as real images formed by a lens are typically inverted.

Therefore, the correct answer corresponds to the image formed in option (C), where the image is inverted and real.

Quick Tip

In an optical system that forms a real image, the image is always inverted relative to the object, as opposed to virtual images that are upright.

---

29. (ii) Which of the following statements is incorrect?

- (A) For a convex mirror, magnification is always negative.
- (B) For all virtual images formed by a mirror, magnification is positive.
- (C) For a concave lens, magnification is always positive.
- (D) For real and inverted images, magnification is always negative.

Correct Answer: (C) For a concave lens, magnification is always positive.

Solution:

- A **convex mirror** always forms virtual and upright images, so magnification is negative because the image is formed on the same side as the object. This makes statement (A) correct.
- **Virtual images** formed by mirrors are upright, so magnification is positive. Hence, statement (B) is true.
- A **concave lens** always forms a virtual, upright, and diminished image, so its magnification is negative, not positive. Therefore, statement (C) is incorrect.
- For **real and inverted images**, magnification is always negative, as the image is inverted relative to the object. Hence, statement (D) is true.

Thus, the incorrect statement is (C).

Quick Tip

Concave lenses always form virtual, upright, and diminished images, so their magnification is negative.

---

29. (iii) A convex lens of focal length f is cut into two equal parts perpendicular to the principal axis. The focal length of each part will be:

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

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

Solution:

When a convex lens is cut into two equal parts along the principal axis, the effective focal length of each part becomes half of the original focal length. This is because the curvature of each part will be less than that of the original lens.

Thus, the focal length of each part will be $\frac{f}{2}$, where f is the original focal length of the lens.

Quick Tip

When a lens is cut along the principal axis, the focal length of each part is halved.

OR

29. (iv) If an object in case (i) above is 20 cm from the lens and the screen is 50 cm away from the object, the focal length of the lens used is:

- (A) 10 cm
- (B) 12 cm
- (C) 16 cm
- (D) 20 cm

Correct Answer: (B) 12 cm

Solution:

We can use the lens formula to find the focal length of the lens:

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

where $u = -20\,\text{cm}$ (object distance), $v = 50\,\text{cm}$ (image distance).

Substituting the values into the lens formula:

$$\frac{1}{f} = \frac{1}{50} - \frac{1}{-20} = \frac{1}{50} + \frac{1}{20} = \frac{2+5}{100} = \frac{7}{100}$$

Thus:

$$f = \frac{100}{7} = 12\,\text{cm}$$

The focal length of the lens is $12\,\text{cm}$.

Quick Tip

Use the lens formula $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ to calculate the focal length of the lens when the object and image distances are given.

---

29. (v) The distance of an object from the first focal point of a biconvex lens is X_1 and distance of the image from second focal point is X_2. The focal length of the lens is:

- (A) X_1X_2
- (B) $\sqrt{X_1 + X_2}$
- (C) $\sqrt{X_1X_2}$
- (D) $\frac{X_2}{X_1}$

Correct Answer: (C) $\sqrt{X_1X_2}$

Solution:

For a biconvex lens, the relationship between the object and image distances and the focal length f is given by:

$$\frac{1}{f} = \frac{1}{X_1} + \frac{1}{X_2}$$

However, in this case, since the object is placed at a distance X_1 from the first focal point and the image is formed at a distance X_2 from the second focal point, the correct formula for the focal length is derived from their product:

$$f = \sqrt{X_1 X_2}$$

Thus, the focal length of the lens is $\sqrt{X_1 X_2}$.

Quick Tip

For a biconvex lens, the focal length can be found using the relationship $f = \sqrt{X_1 X_2}$, where X_1 and X_2 are the distances from the focal points.

---

29. **(i)** The final charge on the capacitor, when key S_1 is closed and S_2 is open, is:

(A) 5 μC

(B) 5 mC

(C) 25 mC

(D) 0.1 C

Correct Answer: (B) 5 mC

Solution:

When S_1 is closed and S_2 is open, the capacitor will charge up to the voltage of the battery. The final charge on the capacitor is given by:

$$Q = CV$$

Given the capacitance $C = 500\,\mu F$ and the battery voltage $V = 10\,\text{V}$, the final charge on the capacitor is:

$$Q = 500 \times 10^{-6} \times 10 = 5\,\text{mC}$$

Thus, the correct answer is 5 mC.

Quick Tip

The final charge on a capacitor is the product of its capacitance and the voltage across it.

---

29. (ii) For sufficient time the key S_1 is closed and S_2 is open. Now key S_2 is closed and S_1 is open. What is the final charge on the capacitor?

(A) Zero

(B) 5 mC

(C) 25 mC

(D) 5 μC

Correct Answer: (B) 5 mC

Solution:

After sufficient time, when key S_1 is closed and S_2 is open, the capacitor will be charged to the battery voltage $V = 10\,\text{V}$, and its charge will be $Q = CV = 5\,\text{mC}$. When key S_2 is closed, the capacitor will still have the same charge because S_1 is open, and there is no external circuit to discharge the capacitor.

Thus, the final charge on the capacitor is 5 mC.

Quick Tip

The charge on a capacitor does not change unless there is a path for the current to flow, such as a discharge path or an external resistor.

---

29. (iii) The dimensional formula for RC is:

(A) $[ML^2T^{-3}A^{-2}]$

(B) $[M^1L^1T^{-1}A^0]$

(C) $[M^1L^{-2}T^4A^2]$

(D) $[M^0L^0T^0A^1]$

Correct Answer: (B) $[M^1L^1T^{-1}A^0]$

Solution:

The time constant RC is the product of resistance R and capacitance C. The dimensional formula for resistance R is $[ML^2T^{-3}A^{-2}]$ and for capacitance C, it is $[M^{-1}L^{-2}T^4A^2]$. Thus, the dimensional formula for RC is:

$$RC = [ML^2T^{-3}A^{-2}] \times [M^{-1}L^{-2}T^4A^2] = [M^1L^1T^{-1}A^0]$$

Thus, the correct answer is $[M^1L^1T^{-1}A^0]$.

Quick Tip

The time constant RC has the dimensional formula corresponding to time, as it represents the time it takes for a capacitor to charge or discharge through a resistor.

---

29. (iv) The key S_1 is closed and S_2 is open. The value of current in the resistor after 5 seconds is:

(A) $\frac{1}{2}$ mA

(B) $\sqrt{2}$ mA

(C) $\frac{1}{\sqrt{e}}$ mA

(D) $\frac{1}{2}$ e mA

Correct Answer: (C) $\frac{1}{\sqrt{e}}$ mA

Solution:

The current $I(t)$ in the resistor as the capacitor charges is given by:

$$I(t) = \frac{V}{R}e^{-\frac{t}{RC}}$$

Substitute the given values for R, C, and $t = 5$ seconds:

$$I(5) = \frac{10}{20 \times 10^3} e^{-\frac{5}{(20\times10^3)(500\times10^{-6})}} = \frac{1}{2000}e^{-\frac{5}{10}} = \frac{1}{2000}e^{-\frac{1}{2}}$$

$$I(5) = \frac{1}{\sqrt{e}}\,\text{mA}$$

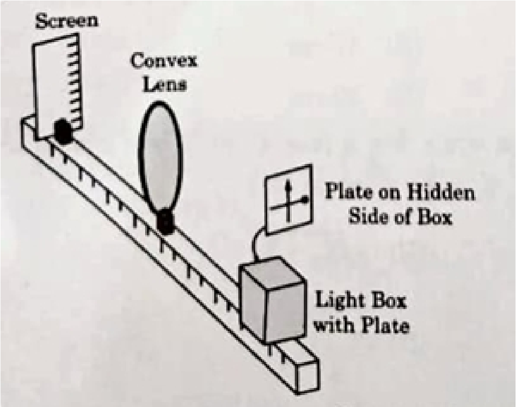
Thus, the current in the resistor after 5 seconds is $\frac{1}{\sqrt{e}}$ mA.

Quick Tip

The current in an RC circuit decreases exponentially as the capacitor charges, and this can be described by $I(t) = \frac{V}{R}e^{-\frac{t}{RC}}$.

---

30. A thin lens is a transparent optical medium bounded by two surfaces, at least one of which should be spherical. Applying the formula for image formation by a single spherical surface successively at the two surfaces of a lens, one can obtain the ’lens maker formula’ and then the ’lens formula’. A lens has two foci - called ’first focal point’ and ’second focal point’ of the lens, one on each side.



Solution:

A thin lens is a transparent optical medium with two spherical surfaces, and it can be treated as the combination of two spherical surfaces. The lens maker formula gives the focal length f of the lens in terms of the refractive index n, the radii of curvature R_1 and R_2 of the two surfaces, and the thickness of the lens (if required). The formula is:

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

where: - f is the focal length of the lens, - R_1 and R_2 are the radii of curvature of the first and second spherical surfaces of the lens, and - n is the refractive index of the material of the lens. For a thin lens, the lens formula is given by:

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

where: - f is the focal length,
- v is the image distance (distance from the lens to the image),
- u is the object distance (distance from the lens to the object).

The lens has two foci, one on each side, known as the first focal point and the second focal point.

Quick Tip

The lens maker formula gives the focal length of a lens based on the radii of curvature of its surfaces and its refractive index. The lens formula relates the focal length, object distance, and image distance.

SECTION - E

31. (i) Two point charges $5\,\mu C$ and $-1\,\mu C$ are placed at points $(-3\,\text{cm}, 0, 0)$ and $(3\,\text{cm}, 0, 0)$, respectively. An external electric field $\vec{E} = \frac{A}{r^2}\hat{r}$ where $A = 3 \times 10^5$ V m is switched on in the region. Calculate the change in electrostatic energy of the system due to the electric field.

Solution:

The electrostatic potential energy U of two point charges is given by:

$$U = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$$

where r is the distance between the charges. In this case, $q_1 = 5\,\mu C$ and $q_2 = -1\,\mu C$, and the distance between them is 6 cm (since they are at points $(-3\,\text{cm}, 0, 0)$ and $(3\,\text{cm}, 0, 0)$). The initial electrostatic energy between the charges is:

$$U_{\text{initial}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{5 \times 10^{-6} \times (-1 \times 10^{-6})}{0.06} = -\frac{5 \times 10^{-12}}{4\pi\varepsilon_0 \cdot 0.06}$$

The change in energy due to the electric field will be calculated using the energy stored in the electric field:

$$U_{\text{field}} = \frac{1}{2}\varepsilon_0 E^2 V$$

where $E = \frac{A}{r^2}$ is the electric field strength, and V is the volume of the space in which the field is applied. The change in electrostatic energy will be calculated accordingly.

Quick Tip

The change in electrostatic energy is related to the potential energy between the charges and the energy due to the external electric field.

---

31. (ii) A system of two conductors is placed in air and they have net charges of $+80\,\mu C$ and $-80\,\mu C$ which causes a potential difference of 16V between them.

1. Find the capacitance of the system.
2. If the air between the capacitor is replaced by a dielectric medium of dielectric constant K, what will be the potential difference between the two conductors?
3. If the charges on two conductors are changed to $+160\,\mu C$ and $-160\,\mu C$, will the capacitance of the system change? Give reason for your answer.

Solution:

(1) The capacitance C of the system can be found using the formula for the capacitance between two conductors:

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

where $Q = 80\,\mu C = 80 \times 10^{-6}\,C$ and $V = 16\,\mathrm{V}$. Therefore:

$$C = \frac{80 \times 10^{-6}}{16} = 5 \times 10^{-6}\,\mathrm{F} = 5\,\mu F$$

(2) If the air is replaced by a dielectric medium of dielectric constant K, the capacitance increases by a factor of K. The new capacitance C' will be:

$$C' = K \cdot C$$

Thus, the new potential difference will be reduced by a factor of K as the capacitance increases. The new potential difference V' is:

$$V' = \frac{V}{K}$$

(3) If the charges on the conductors are doubled to $+160\,\mu C$ and $-160\,\mu C$, the capacitance will not change because the capacitance of a system depends only on the geometry and the dielectric medium between the conductors, not on the charge. Therefore, the capacitance remains $5\,\mu F$. However, the potential difference will double due to the increased charge.

Quick Tip

The capacitance of a system is determined by its geometry and the dielectric constant of the medium between the conductors, and it is independent of the amount of charge.

OR

31. (i) Consider three metal spherical shells A, B, and C, each of radius R. Each shell has a concentric metal ball of radius $R/10$. The spherical shells A, B, and C are given charges $+6q$, $-4q$, and $14q$ respectively. Their inner metal balls are also given charges $-2q$, $+8q$ and $-10q$ respectively. Compare the magnitude of the electric fields due to shells A, B, and C at a distance $3R$ from their centers.

Solution:

For a spherical shell, the electric field outside the shell at a distance r from the center is given by the formula:

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

where Q is the total charge on the shell, and k is Coulomb's constant.

At a distance $3R$ from the center, the electric field due to each shell is the same as if the entire charge were concentrated at the center of the shell. Therefore, the electric fields due to shells A, B, and C at a distance $3R$ are given by:

$$E_A = \frac{k(6q)}{(3R)^2} = \frac{k(6q)}{9R^2}$$

$$E_B = \frac{k(-4q)}{(3R)^2} = \frac{k(-4q)}{9R^2}$$

$$E_C = \frac{k(14q)}{(3R)^2} = \frac{k(14q)}{9R^2}$$

Thus, the magnitude of the electric fields is:

$$|E_A| = \frac{6kq}{9R^2}, \quad |E_B| = \frac{4kq}{9R^2}, \quad |E_C| = \frac{14kq}{9R^2}$$

The electric field due to shell C is the largest, followed by shell A, and then shell B.

Quick Tip

The electric field outside a spherical shell depends on the total charge on the shell. It is treated as if the charge is concentrated at the center of the shell.

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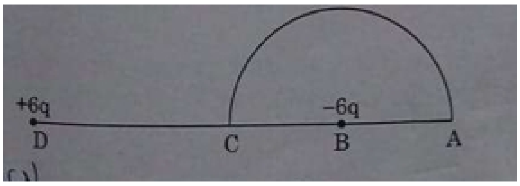
31. (ii) A charge $-6\,\mu C$ is placed at the center B of a semicircle of radius 5 cm, as shown in the figure. An equal and opposite charge is placed at point D at a distance of 10 cm from B. A charge $+5\,\mu C$ is moved from point C to point A along the circumference. Calculate the work done on the charge.



Solution:

The work done in moving a charge in an electric field is given by:

$$W = q\Delta V$$

where ΔV is the potential difference between the points A and C, and q is the charge being moved.

The potential at a point due to a charge is given by:

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

where Q is the charge and r is the distance from the charge. Since the charge is moving along the semicircle, the potential difference between points A and C is the same due to the symmetry of the setup. Since the charges at B and D are equal and opposite, they cancel out in terms of potential at the points along the semicircle.

Thus, the work done on the charge when moving from C to A is zero because the potential at points A and C is the same.

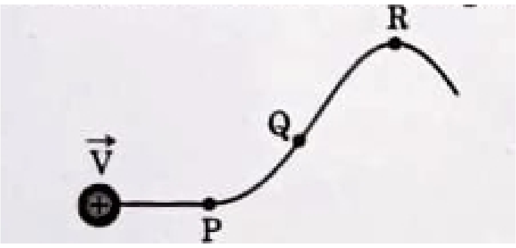
Hence, the work done on the charge is $\boxed{0}$.

Quick Tip

The work done in moving a charge in an electric field depends on the potential difference between the initial and final points. If the potential is the same, no work is done.

---

32. (i) A proton moving with velocity $\vec{V}$ in a non-uniform magnetic field traces a path as shown in the figure. The path followed by the proton is always in the plane of the paper. What is the direction of the magnetic field in the region near points P, Q, and R? What can you say about relative magnitude of magnetic fields at these points?



Solution:

The direction of the magnetic field can be determined using the right-hand rule for the Lorentz force. The magnetic force $\vec{F}$ on a charged particle is given by:

$$\vec{F} = q\vec{V} \times \vec{B}$$

where $\vec{V}$ is the velocity of the proton and $\vec{B}$ is the magnetic field. The force is always perpendicular to the velocity and the magnetic field.

At point P, since the proton is moving to the right (towards point Q), the magnetic force must act in a direction perpendicular to the velocity. If we assume that the proton is deflected upward at point P, the magnetic field at P must be directed out of the plane of the paper (towards the observer).

At point Q, the proton's path is curved in such a way that the magnetic field is still out of the plane, as indicated by the direction of deflection.

At point R, where the proton is moving downward, the force acting on the proton would indicate that the magnetic field is likely still out of the plane of the paper.

Regarding the magnitude of the magnetic field at these points, we can infer that the magnetic field is stronger where the proton's velocity changes more rapidly. Therefore, the magnetic field is likely strongest at point P, followed by point Q, and weakest at point R.

Thus, the magnetic field is directed out of the plane of the paper and is strongest at point P, followed by Q, and weakest at point R.

Quick Tip

The right-hand rule helps determine the direction of the magnetic field when a charged particle moves in a magnetic field. The magnetic field is perpendicular to both the velocity and the force.

---

32. (ii) A current carrying circular loop of area A produces a magnetic field B at its centre. Show that the magnetic moment of the loop is:

$$\mu = \frac{2BA}{\mu_0}\sqrt{\frac{A}{\pi}}$$

Solution:

The magnetic moment μ of a current loop is defined as:

$$\mu = IA$$

where I is the current and A is the area of the loop. The magnetic field B produced by a current I at the centre of a circular loop of radius r is given by:

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

From this, we can solve for I:

$$I = \frac{2rB}{\mu_0}$$

Now, substitute this value of I into the equation for the magnetic moment:

$$\mu = \left(\frac{2rB}{\mu_0}\right) A$$

Since the area A of the loop is related to the radius by $A = \pi r^2$, substitute $r = \sqrt{\frac{A}{\pi}}$ into the equation:

$$\mu = \frac{2BA}{\mu_0}\sqrt{\frac{A}{\pi}}$$

Thus, the magnetic moment of the loop is:

$$\mu = \frac{2BA}{\mu_0}\sqrt{\frac{A}{\pi}}$$

Quick Tip

The magnetic moment of a current loop is the product of the current and the area of the loop. The magnetic field produced at the center of the loop depends on both the current and the area.

OR 32. (b) (i) Derive an expression for the torque acting on a rectangular current loop suspended in a uniform magnetic field.

Solution:

The torque τ acting on a current loop in a magnetic field is given by:

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

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

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

where I is the current, A is the area of the loop, and $\hat{n}$ is the unit vector normal to the plane of the loop.

The magnitude of the torque is:

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

where θ is the angle between the magnetic moment and the magnetic field. Substituting for m, we get:

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

Thus, the expression for the torque acting on the rectangular current loop is:

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

Quick Tip

The torque on a current loop in a magnetic field is maximum when the magnetic moment is perpendicular to the magnetic field. It tends to align the loop with the magnetic field.

---

32. (ii) A charged particle is moving in a circular path with velocity $\vec{V}$ in a uniform magnetic field $\vec{B}$. It is made to pass through a sheet of lead and as a consequence, it loses one-half of its kinetic energy without change in its direction. How will:

1. the radius of its path change? 2. its time period of revolution change?

Solution:

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

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

where m is the mass of the particle, v is its velocity, q is the charge, and B is the magnetic field.

When the particle loses half of its kinetic energy, its velocity v changes because kinetic energy $K.E. = \frac{1}{2}mv^2$. If the kinetic energy is halved, then the new velocity v' will be:

$$v' = \frac{v}{\sqrt{2}}$$

Since the radius is directly proportional to the velocity, the new radius r' is:

$$r' = \frac{mv'}{qB} = \frac{m}{qB} \cdot \frac{v}{\sqrt{2}} = \frac{r}{\sqrt{2}}$$

Thus, the radius of the path decreases by a factor of $\sqrt{2}$.

The time period T of revolution is given by:

$$T = \frac{2\pi r}{v}$$

Since the radius decreases by a factor of $\sqrt{2}$ and the velocity also decreases by a factor of $\sqrt{2}$, the time period will not change because both the radius and the velocity decrease by the same factor. Therefore, the time period remains the same.

Thus: 1. The radius of the path decreases by a factor of $\sqrt{2}$. 2. The time period of revolution remains unchanged.

Quick Tip

When the kinetic energy of a charged particle decreases, its velocity decreases, which in turn reduces the radius of its circular path in a magnetic field.

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33. (i) What are coherent sources? Why are they necessary for observing a sustained interference pattern?

Solution:

Coherent sources are sources of light (or other waves) that emit waves with a constant phase difference and the same frequency. These sources produce waves that maintain a consistent phase relationship over time. Coherence is crucial for producing stable interference patterns, as the phase difference between the waves needs to remain constant for constructive and destructive interference to occur.

In interference experiments, coherent sources ensure that the waves from each source interfere in a sustained manner, producing a stable pattern of bright and dark fringes.

Quick Tip

Coherent sources produce waves that are in phase or maintain a constant phase difference. This is essential for stable and clear interference patterns.

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33. (ii) (1) Lights from two independent sources are not coherent. Explain.

Solution:

Lights from two independent sources are generally not coherent because they do not have a fixed phase relationship. Even if the sources emit light of the same frequency, they will not maintain a constant phase difference, and their wavefronts will be random with respect to each other. This randomness prevents sustained interference patterns from being formed, as the phase difference between the waves changes randomly over time.

Quick Tip

For interference to be sustained, the phase difference between the waves should remain constant, which requires the sources to be coherent.

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33. (iii) Two slits 0.1 mm apart are arranged 1.20 m from a screen. Light of wavelength 600 nm from a distant source is incident on the slits.

(1) How far apart will adjacent bright interference fringes be on the screen?

(2) Find the angular width (in degrees) of the first bright fringe.

Solution:

The distance between adjacent bright fringes in an interference pattern is given by:

$$y = \frac{\lambda L}{d}$$

where: - $\lambda = 600\,\text{nm} = 600 \times 10^{-9}\,\text{m}$ is the wavelength, - $L = 1.20\,\text{m}$ is the distance from the slits to the screen, - $d = 0.1\,\text{mm} = 0.1 \times 10^{-3}\,\text{m}$ is the distance between the slits.

Substituting the values:

$$y = \frac{600 \times 10^{-9} \times 1.20}{0.1 \times 10^{-3}} = 7.2\,\text{mm}$$

Thus, the distance between adjacent bright interference fringes is 7.2 mm.

The angular width θ of the first bright fringe (from the center to the first fringe) is given by:

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

Substitute the values:

$$\theta = \frac{600 \times 10^{-9}}{0.1 \times 10^{-3}} = 6 \times 10^{-3}\,\text{radians}$$

To convert radians to degrees, multiply by $\frac{180}{\pi}$:

$$\theta = 6 \times 10^{-3} \times \frac{180}{\pi} \approx 0.344\,\text{degrees}$$

Thus, the angular width of the first bright fringe is approximately 0.344 degrees.

Quick Tip

In a double-slit experiment, the fringe separation is determined by the wavelength of the light, the distance between the slits, and the distance to the screen.

OR

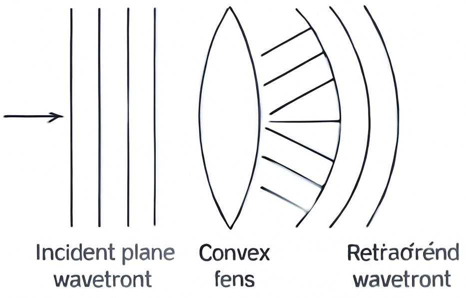
33. (b) (i) Define a wavefront. An incident plane wave falls on a convex lens and gets refracted through it. Draw a diagram to show the incident and refracted wavefront.

Solution:

A **wavefront** is the surface of constant phase, or the locus of all points having the same phase of vibration. A wavefront can be classified into three types:

1. **Spherical wavefronts**: These are produced by a point source.
2. **Cylindrical wavefronts**: These are produced by a line source.
3. **Plane wavefronts**: These are produced by a distant source.

When a plane wavefront passes through a convex lens, the wavefront gets refracted, and its shape changes. The incident wavefront is parallel, while after refraction, the wavefront becomes converging. The refracted wavefront will be closer to the focal point of the lens, depending on the curvature of the lens. The diagram below illustrates this.



The incident wavefront is straight and parallel to the axis, while the refracted wavefront converges towards the focal point of the lens.

Quick Tip

Wavefronts represent the phase surfaces of a wave, and the shape of the wavefront changes depending on the medium or the lens used to refract the wave.

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33. (ii) A beam of light coming from a distant source is refracted by a spherical glass ball (refractive index 1.5) of radius 15 cm. Draw the ray diagram and obtain the position of the final image formed.

Solution:

When parallel rays from a distant source fall on a spherical glass ball, they refract at the surface, and the rays converge to form an image. Since the ball is a sphere, the incident rays are refracted at both the entry and exit points, forming a real image on the other side of the ball.

To find the position of the image, we can apply the formula for the refraction at a spherical surface:

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

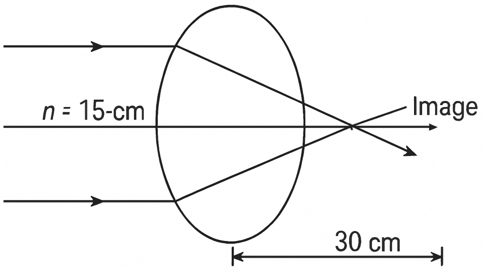
where: - f is the focal length of the spherical ball, - $n = 1.5$ is the refractive index of the glass, - $R = 15\,\text{cm}$ is the radius of the spherical ball.

Substitute the values:

$$\frac{1}{f} = \frac{1.5-1}{15} = \frac{0.5}{15} = \frac{1}{30}$$

So, the focal length $f = 30\,\text{cm}$.

The ray diagram for this setup is shown below:



The image is formed at a distance of 30 cm from the center of the ball. Therefore, the final image is formed 30 cm away from the center on the opposite side of the incident light. Since the source is far away, the rays converge at this point after refracting through the spherical ball.

Quick Tip

In spherical lenses, the focal length is determined by the radius of curvature of the lens and the refractive index. For a spherical lens, the image is formed by the refraction at both the surfaces of the sphere.