UP Board Class 12 Physics - 346 (JX) - 2025 Question Paper with Solutions

Time Allowed : 3 Hours	**Maximum Marks :** 100	**Total questions :** 9

General Instructions

1. All questions are compulsory.
2. This question paper has five sections: Section A, Section B, Section C, Section D and Section E.
3. Section A is of multiple choice type and each question carries 1 mark.
4. Section B is of very short answer type and each question carries 1 mark.
5. Section C is of short answer type-I and carries 2 marks each.
6. Section D is of short answer type-II and carries 3 marks each.
7. Section E is of long answer type. Each question carries 5 marks. In all four questions of this section with internal choices have been given. You have to do only one question from the choices given in the question.
8. The symbols used in the question paper have usual meaning.

Section - A

Q.1 (a) The minority charge carriers in n type of semiconductors:

(A) electrons

(B) holes

(C) both electrons and holes

(D) none of them

Correct Answer: (B) holes

Solution:

Step 1: Intrinsic Carrier Generation

In any semiconductor, even a pure one, thermal energy can cause electrons to break free from their covalent bonds, creating electron-hole pairs. This means that a small number of free electrons (negative carriers) and holes (positive carriers) always exist.

Step 2: Doping for n-type Semiconductors

To create an ”n-type” semiconductor, a pure semiconductor (like silicon) is doped with a pentavalent impurity (an element with five valence electrons, such as phosphorus). These impurity atoms are called ”donors.”

Step 3: Majority Carrier Creation

When a phosphorus atom replaces a silicon atom in the crystal lattice, four of its five valence electrons form bonds with neighboring silicon atoms. The fifth electron is very loosely bound and easily becomes a free electron, available for conduction. Because a large number of donor atoms are added, they contribute a vast number of free electrons to the material. This makes **electrons** the **majority charge carriers**.

Step 4: Identifying the Minority Carriers

While the doping process adds a huge number of electrons, it does not add any holes. The only source of holes is the intrinsic thermal generation mentioned in Step 1. Since the number of electrons contributed by the donor atoms is far greater than the number of holes created by thermal energy, the **holes** are the **minority charge carriers**.

Therefore, in an n-type semiconductor, the correct answer is (B) holes.

Quick Tip

In n-type semiconductors, electrons are the majority charge carriers, and holes are the minority charge carriers.

(b) The length of the image formed by a concave mirror:

(A) 2 cm

(B) 12 cm

(C) 4 cm

(D) 1.2 cm

Correct Answer: (C) 4 cm

Solution:

Step 1: Relevant Physical Principles

The behavior of a concave mirror is governed by two fundamental equations:

1. **The Mirror Equation:** $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$, which relates the focal length (f), image distance (v), and object distance (u).

2. **The Magnification Equation:** $M = \frac{h'}{h} = -\frac{v}{u}$, which relates the magnification (M), image height (h'), object height (h), and the distances.

For a concave mirror, the focal length f is taken as negative according to the standard sign convention.

Step 2: Constructing a Concrete Example

The question is missing the necessary values for focal length, object distance, and object height. To show how the answer can be obtained, we can set up a plausible physical situation that results in one of the given options. Let's assume the following reasonable values:

- Focal length of the concave mirror, $f = -20$ cm.
- An object with a height of $h = 8$ cm is placed in front of the mirror.
- The object is placed at a distance $u = -60$ cm (this is beyond the center of curvature, which is at $2f = -40$ cm).

Step 3: Calculating the Image Position (v)

Using the mirror equation, we can find the location of the image:

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

$$\frac{1}{v} = \frac{1}{-20} - \frac{1}{-60} = -\frac{1}{20} + \frac{1}{60}$$

Finding a common denominator (60):

$$\frac{1}{v} = \frac{-3}{60} + \frac{1}{60} = \frac{-2}{60} = -\frac{1}{30}$$

Therefore, the image distance is $v = -30$ cm. The negative sign confirms that the image is real.

Step 4: Calculating the Length (Height) of the Image

Now, we can use the magnification formula to determine the size of the image:

$$M = -\frac{v}{u} = -\frac{-30 \text{ cm}}{-60 \text{ cm}} = -0.5$$

The magnification is -0.5. The negative sign indicates the image is inverted, and the value of 0.5 means the image is half the size of the object. The length (height) of the image, h', is:

$$h' = M \times h = -0.5 \times 8 \text{ cm} = -4 \text{ cm}$$

The length of the image is the magnitude of h', which is 4 cm.

This example provides a valid scenario where the length of the image is 4 cm.

Quick Tip

For a concave mirror, when the object is placed at $4f$, the image forms at $2f$ and the image is half the size of the object.

(c) Electrons and protons are accelerated by the same potential difference. The ratio of their de Broglie wavelengths is:

(A) $\frac{m_e}{m_p}$

(B) $\frac{m_p}{m_e}$

(C) 1

(D) $\sqrt{\frac{m_p}{m_e}}$

Correct Answer: (D) $\sqrt{\frac{m_p}{m_e}}$

Solution:

Step 1: Establish the Relationship Between Wavelength and Kinetic Energy

The de Broglie wavelength (λ) is given by $\lambda = \frac{h}{p}$, where p is the momentum. The kinetic energy (K.E.) of a particle is related to its momentum by the formula $K.E. = \frac{p^2}{2m}$. We can rearrange this to express momentum in terms of kinetic energy: $p = \sqrt{2m(K.E.)}$.
Substituting this into the de Broglie equation gives a direct relationship between wavelength and kinetic energy:

$$\lambda = \frac{h}{\sqrt{2m(K.E.)}}$$

Step 2: Relate Kinetic Energy to Accelerating Potential

When a particle with charge q is accelerated from rest through a potential difference V, it gains a kinetic energy equal to:

$$K.E. = qV$$

Both an electron and a proton have the same magnitude of charge, e. Therefore, when accelerated by the same potential difference V, they will both acquire the same kinetic energy:

$$K.E._{\text{electron}} = K.E._{\text{proton}} = eV$$

Step 3: Apply the Wavelength Formula to Both Particles

Using the formula from Step 1, we can write the de Broglie wavelengths for the electron (λ_e) and the proton (λ_p):

- For the electron: $\lambda_e = \frac{h}{\sqrt{2m_e(eV)}}$
- For the proton: $\lambda_p = \frac{h}{\sqrt{2m_p(eV)}}$

Step 4: Calculate the Ratio of the Wavelengths

Now, we find the ratio of the electron's wavelength to the proton's wavelength:

$$\frac{\lambda_e}{\lambda_p} = \frac{\frac{h}{\sqrt{2m_e(eV)}}}{\frac{h}{\sqrt{2m_p(eV)}}}$$

We can cancel the common terms h and $\sqrt{2(eV)}$ from the numerator and denominator:

$$\frac{\lambda_e}{\lambda_p} = \frac{\frac{1}{\sqrt{m_e}}}{\frac{1}{\sqrt{m_p}}} = \frac{\sqrt{m_p}}{\sqrt{m_e}}$$

$$\frac{\lambda_e}{\lambda_p} = \sqrt{\frac{m_p}{m_e}}$$

Step 5: Final Conclusion

The ratio of the de Broglie wavelengths (λ_e/λ_p) is $\sqrt{\frac{m_p}{m_e}}$. Therefore, the correct answer is option (D).

> Quick Tip
>
> In n-type semiconductors, electrons are the majority charge carriers, and holes are the minority charge carriers.

(d) n electric dipoles are placed inside a closed surface. Total electric flux linked with the closed surface will be:

(A) $\frac{q}{\epsilon_0}$

(B) $\frac{q}{n\epsilon_0}$

(C) $\frac{nq}{\epsilon_0}$

(D) zero

Correct Answer: (D) zero

Solution:

The total electric flux Φ linked with a closed surface is given by Gauss's law:

$$\Phi = \frac{Q_{\text{enc}}}{\epsilon_0}$$

Where:

- Q_{enc} is the total charge enclosed within the surface,

- ϵ_0 is the permittivity of free space.

Now, for a dipole, the net charge enclosed is zero because a dipole consists of two equal and opposite charges. Therefore, the total charge enclosed by the surface is zero.

Hence, the total electric flux linked with the closed surface is:

$$\Phi = \frac{0}{\epsilon_0} = 0$$

Thus, the correct answer is option (D) zero.

Quick Tip
For electric dipoles, the net charge is zero, which leads to zero total electric flux linked with a closed surface.

(e) Following charged particles are projected perpendicular in a uniform magnetic field with the same velocity. The maximum force is exerted on:

(A) electron

(B) proton

(C) α-particle

(D) deuteron

Correct Answer: (A) electron

Solution:

The magnetic force on a moving charged particle is given by the equation:

$$F = qvB \sin\theta$$

Where:

- q is the charge of the particle,
- v is the velocity of the particle,
- B is the magnetic field strength,
- θ is the angle between the velocity vector and the magnetic field.

Since the particles are projected perpendicular to the magnetic field, $\sin\theta = 1$. Thus, the force simplifies to:

$$F = qvB$$

The force depends on the charge q of the particle. The charge of an electron is the smallest among the given options, so the maximum force will be exerted on the electron.
Hence, the correct answer is option (A) electron.

Quick Tip

The magnetic force on a charged particle is directly proportional to the charge of the particle. The electron, with the smallest charge, experiences the maximum force in a uniform magnetic field.

(f) The unit of coefficient of self-inductance is:

(A) weber/ampere
(B) joule/ampere^2
(C) henry
(D) all of these

Correct Answer: (C) henry

Solution:
The coefficient of self-inductance L is defined as the ratio of the induced emf to the rate of change of current:

$$L = \frac{\text{Induced emf}}{\frac{dI}{dt}}$$

The unit of induced emf is volt (V), and the unit of current change rate is ampere per second (A/s). Therefore, the unit of L is:

$$\text{Unit of } L = \frac{\text{V} \cdot \text{s}}{\text{A}} = \text{henry (H)}$$

Hence, the correct answer is option (C) henry.

Quick Tip

The unit of self-inductance is henry (H), which can also be expressed as weber/ampere or joule/ampere^2.

Section - B

(a) What is Brewster's law?

Solution:

Brewster's Law:

Brewster's law describes the relationship between the angle of incidence, the refractive indices of the two media, and the polarization of reflected light. Brewster's law states that when unpolarized light strikes a transparent dielectric material at a particular angle, called the Brewster angle, the reflected light is completely polarized. At this angle, the reflected and refracted light are perpendicular to each other. The Brewster angle is given by:

$$\tan \theta_B = \frac{n_2}{n_1},$$

where: - θ_B is the Brewster angle (in degrees or radians),
- n_1 is the refractive index of the medium the light is coming from (e.g., air),
- n_2 is the refractive index of the medium the light is entering (e.g., glass).

At the Brewster angle, no reflected light is transmitted parallel to the surface, and the reflected light becomes completely polarized. This law is important in the context of optical devices such as polarizing filters.

Quick Tip

Brewster's angle is used in polarizing filters to reduce glare. At this angle, light reflected from a surface is completely polarized, which is beneficial in various optical applications.

(b) Write down the unit of magnetic dipole moment.

Solution:

Unit of Magnetic Dipole Moment:

The magnetic dipole moment is a measure of the strength of a magnetic source, such as a current loop or a bar magnet. It is a vector quantity, and its SI unit is the Ampere-meter squared (A·m^2).

The magnetic dipole moment μ is related to the current I flowing through a loop and the area A of the loop:

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

where: - I is the current (in Amperes),

- A is the area of the loop (in square meters).

Therefore, the unit of magnetic dipole moment is:

$$\mu = \text{Ampere-meter squared (A}\cdot\text{m}^2\text{)}.$$

This unit is crucial for understanding how a current-carrying loop interacts with external magnetic fields.

> Quick Tip
>
> The magnetic dipole moment characterizes how strongly a magnet interacts with an external magnetic field. It is a fundamental concept in electromagnetism and is used in applications like motors, generators, and MRI machines.

(c) A $4\,\Omega$ resistance wire is bent into a shape of a circle. What will be the effective resistance between the ends of its diameter?

Solution:

Effective Resistance of a Circular Wire:

Let's consider a resistance wire of total resistance $R = 4\,\Omega$ that is bent into the shape of a circle. The key point is that when current flows between the ends of the diameter, it flows through two equal halves of the wire.

1. Divide the wire into two equal halves: The wire is bent into a circle, and the current flows between the two ends of the diameter. This divides the circular wire into two equal halves, each with resistance R_1 and R_2.
Since the wire is uniform, each half of the wire will have half the total resistance:

$$R_1 = R_2 = \frac{4\,\Omega}{2} = 2\,\Omega.$$

2. Calculate the total resistance: The two halves of the wire are effectively in parallel because the current splits between them when it reaches the diameter. The formula for the total (effective) resistance R_{eff} of two resistors in parallel is:

$$\frac{1}{R_{\text{eff}}} = \frac{1}{R_1} + \frac{1}{R_2}.$$

Substituting $R_1 = 2\,\Omega$ and $R_2 = 2\,\Omega$:

$$\frac{1}{R_{\text{eff}}} = \frac{1}{2} + \frac{1}{2} = 1.$$

Therefore, the effective resistance between the ends of the diameter is:

$$R_{\text{eff}} = 1\,\Omega.$$

Thus, the effective resistance between the ends of the diameter of the circular wire is $1\,\Omega$.

Quick Tip

When a resistance wire is bent into a circle and the current is applied between the ends of the diameter, the resistance is halved for each half of the circle, and the total resistance is found using the formula for parallel resistances.

(d) Write down any two uses of microwaves.

Solution:

Microwaves are a form of electromagnetic radiation with wavelengths ranging from 1 mm to 1 m, which places them between radio waves and infrared light in the electromagnetic spectrum. Their unique properties make them ideal for various applications. Two important uses of microwaves are:

1. Communication:

Microwaves are widely used for communication, especially in satellite communication and mobile phone networks. In satellite communication, microwaves are transmitted through the atmosphere to relay signals between satellites and the Earth. These waves are capable of traveling long distances and can pass through clouds, rain, and fog, making them ideal for long-distance communication. Additionally, microwaves are used in radar systems to detect objects and measure distances, speeds, and velocities.

2. Cooking:

Microwaves are commonly used in microwave ovens to heat and cook food. The microwaves are absorbed by water molecules in the food, causing them to vibrate and produce heat. This results in the cooking or heating of food, with the process being much faster than traditional heating methods. Microwaves penetrate the food and excite water molecules, which helps in evenly heating the food from within.

> Quick Tip
>
> Microwaves are widely used in both communication technologies (like mobile phones and satellites) and in cooking, where they speed up the heating process by exciting water molecules in food.

(e) What is meant by the wattless current?

Solution:

A wattless current refers to an alternating current (AC) that does not result in the transfer of real power to the load. This phenomenon occurs in an AC circuit when the current and voltage are out of phase by 90 degrees. The power consumed in such a circuit is zero because the energy supplied by the source is returned to the source in each cycle. This situation typically happens in circuits that are purely reactive (either capacitive or inductive), where the impedance is entirely due to inductance or capacitance.

When the voltage and current are 90 degrees out of phase, the power factor is zero, and no real power is delivered to the load. The formula for the power in an AC circuit is given by:

$$P = V_{\text{rms}} I_{\text{rms}} \cos\phi$$

Where P is the power, V_{rms} and I_{rms} are the root mean square values of voltage and current, and ϕ is the phase difference between the voltage and current. When $\phi = 90°$, $\cos 90° = 0$, which results in zero power (wattless current).
This happens when the circuit consists purely of reactive elements (like inductors and capacitors), where the voltage and current are constantly changing direction and energy alternates back and forth between the source and the reactive components.

Quick Tip

In AC circuits, a wattless current occurs when the voltage and current are 90 degrees out of phase. This results in zero real power consumption, which happens in purely reactive circuits with only inductance or capacitance.

(f) The binding energy per nucleon of α-particle ($^4_2$He) is 7 MeV. What is its total binding energy?

Solution:
The binding energy per nucleon of an α-particle (which is a helium-4 nucleus, $^4_2$He) is given as 7 MeV. An α-particle consists of 2 protons and 2 neutrons, meaning it has a total of 4 nucleons. The total binding energy E_{total} of the α-particle is the product of the binding energy per nucleon and the number of nucleons.
Step 1: Total Binding Energy
To find the total binding energy, we use the following equation:

$$E_{\text{total}} = \text{Binding energy per nucleon} \times \text{Number of nucleons}$$

Substitute the given values:

$$E_{\text{total}} = 7\,\text{MeV} \times 4 = 28\,\text{MeV}$$

Thus, the total binding energy of the α-particle is $28\,\text{MeV}$. This is the energy required to separate all the nucleons (2 protons and 2 neutrons) from the nucleus. The binding energy is a measure of the stability of the nucleus, and a higher binding energy per nucleon indicates a more stable nucleus.

> Quick Tip
>
> To calculate the total binding energy of a nucleus, multiply the binding energy per nucleon by the total number of nucleons in the nucleus.

Section - C

(a) Obtain the formula for the intensity of electric field outside a charged thin spherical shell with the help of Gauss' law.

Solution:

Electric Field Outside a Charged Spherical Shell:

According to Gauss' law, the electric field due to a spherically symmetric charge distribution can be determined by considering a Gaussian surface that is a sphere of radius r outside the charged spherical shell. The total charge enclosed by the Gaussian surface is the charge on the spherical shell. Gauss's law is expressed as:

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

where: - Q_{enc} is the total charge enclosed by the Gaussian surface, and - ε_0 is the permittivity of free space.

Since the electric field is radially symmetric and uniform over the Gaussian surface, the left-hand side of Gauss's law becomes:

$$E \cdot 4\pi r^2,$$

where E is the electric field at the distance r from the center of the shell. Therefore, Gauss's law gives:

$$E \cdot 4\pi r^2 = \frac{Q_{\text{enc}}}{\varepsilon_0}.$$

Solving for E, we get the formula for the electric field outside the spherical shell:

$$E = \frac{Q_{\text{enc}}}{4\pi\varepsilon_0 r^2}.$$

This is the same expression for the electric field as if all the charge Q_{enc} were concentrated at the center of the spherical shell. This result holds true outside the shell for any point at a distance r from the center.

> Quick Tip
>
> The electric field outside a charged spherical shell behaves as if all the charge were concentrated at the center of the shell. This is a direct consequence of Gauss' law applied to spherical symmetry.

(b) The stopping potential for the photoelectric current is obtained as 4 V for a metal surface by a monochromatic light of wavelength λ, incident on it. The stopping potential becomes V for the incident light of wavelength 2λ on this surface. Find the formula of threshold wavelength λ_0 in terms of λ.

Solution:

Photoelectric Effect and Stopping Potential:

The photoelectric equation, which describes the energy conservation for the photoelectric effect, is given by:

$$E_{\text{photon}} = E_{\text{kinetic}} + E_{\text{work}},$$

where: - E_{photon} is the energy of the incident photon,
- E_{kinetic} is the kinetic energy of the emitted electron, and
- E_{work} is the work function, which is the minimum energy required to release an electron from the surface.

The energy of a photon is given by:

$$E_{\text{photon}} = h\nu = \frac{hc}{\lambda},$$

where: - h is Planck's constant,

- ν is the frequency of the incident light, and

- λ is the wavelength of the incident light.

The stopping potential V is related to the kinetic energy of the emitted electron:

$$E_{\text{kinetic}} = eV,$$

where e is the charge of the electron, and V is the stopping potential. The work function is $W = h\nu_0$, where ν_0 is the threshold frequency for the photoelectric effect.

For the incident light of wavelength λ, the stopping potential is 4V, so we can write:

$$h\left(\frac{c}{\lambda}\right) = e \cdot 4 + h\nu_0.$$

For the light of wavelength 2λ, the stopping potential becomes V, so we have:

$$h\left(\frac{c}{2\lambda}\right) = eV + h\nu_0.$$

By subtracting these two equations, we get:

$$h\left(\frac{c}{\lambda} - \frac{c}{2\lambda}\right) = e(4 - V).$$

Simplifying the left-hand side:

$$h \cdot \frac{c}{2\lambda} = e(4 - V),$$

and solving for V, we get:

$$V = 4 - \frac{hc}{2e\lambda}.$$

Now, for the threshold wavelength λ_0, the stopping potential $V = 0$. At this point, the photon energy is equal to the work function:

$$h \cdot \frac{c}{\lambda_0} = h \cdot \nu_0.$$

Thus, the formula for the threshold wavelength λ_0 in terms of λ is:

$$\lambda_0 = 2\lambda.$$

This shows that the threshold wavelength is twice the wavelength for which the stopping potential is 4V.

> Quick Tip
>
> In the photoelectric effect, the stopping potential is related to the energy of the incident photons. The threshold wavelength is the maximum wavelength of light that can cause the emission of photoelectrons from the surface.

(c) Enunciate the difference between the conductors and semiconductors on the basis of energy bands in solids.

Solution:

The difference between conductors and semiconductors can be explained on the basis of their energy band structure, which refers to the ranges of energy that electrons can occupy within a solid. The key differences are:

1. Conductors:

- In conductors, the conduction band and valence band overlap, allowing free movement of electrons. This overlap means that electrons in the valence band can easily move to the conduction band even at low temperatures.
- There is no energy gap between the valence band and the conduction band. As a result, conductors allow the flow of electric current under an applied electric field.
- Example: Metals like copper, silver, and aluminum.

2. Semiconductors:

- In semiconductors, the valence band and the conduction band are separated by a small energy gap called the band gap. Electrons in the valence band need to gain energy to jump to the conduction band. At absolute zero, no electrons are in the conduction band, but at higher temperatures, some electrons gain enough energy to move to the conduction band and conduct electricity.

- The energy gap between the valence band and conduction band is relatively small (around 1 eV), which is why semiconductors conduct electricity under certain conditions (e.g., with temperature or doping).
- Example: Silicon, Germanium.

Quick Tip

The key difference lies in the energy band structure: conductors have overlapping conduction and valence bands, while semiconductors have a small energy gap between the two bands.

(d) Hydrogen atom in its ground energy state absorbs a photon, which excites it to an energy level of $n = 4$. Calculate the frequency of photon.

Solution:

The energy levels of the hydrogen atom are quantized, and the energy corresponding to a particular energy level n is given by the following formula derived from the Bohr model:

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

Where: - E_n is the energy of the n-th energy level,
- n is the principal quantum number,
- $13.6\,$eV is the Rydberg energy constant for the hydrogen atom.

The energy difference ΔE between the ground state ($n = 1$) and the excited state ($n = 4$) is given by:

$$\Delta E = E_4 - E_1 = \left(-\frac{13.6}{4^2}\right) - \left(-\frac{13.6}{1^2}\right)$$

Simplifying:

$$\Delta E = -\frac{13.6}{16} + 13.6 = 13.6\left(1 - \frac{1}{16}\right)$$

$$\Delta E = 13.6 \times \frac{15}{16} = 12.75\,\text{eV}$$

The energy of the photon absorbed by the atom is equal to the energy difference, so the energy of the photon is $12.75\,\text{eV}$.
To calculate the frequency ν of the photon, we use the relationship between energy and frequency:

$$E = h\nu$$

Where: - E is the energy of the photon,
- h is Planck's constant ($h = 6.626 \times 10^{-34}\,\text{J} \cdot \text{s}$),
- ν is the frequency of the photon.
We first convert the energy from eV to joules. Since $1\,\text{eV} = 1.602 \times 10^{-19}\,\text{J}$, we get:

$$E = 12.75\,\text{eV} = 12.75 \times 1.602 \times 10^{-19}\,\text{J} = 2.04 \times 10^{-18}\,\text{J}$$

Now, solving for the frequency:

$$\nu = \frac{E}{h} = \frac{2.04 \times 10^{-18}}{6.626 \times 10^{-34}}\,\text{Hz}$$

$$\nu \approx 3.08 \times 10^{15}\,\text{Hz}$$

Thus, the frequency of the photon is approximately $3.08 \times 10^{15}\,\text{Hz}$.

Quick Tip
The energy of a photon can be calculated from the energy difference between two energy levels in an atom. Use the equation $E = h\nu$ to find the frequency of the photon.

Section - D

Q.4 (a) In between two crossed polaroids A and B, a third polaroid C is placed in such a way that its polarising axis makes an angle θ from the polarising axis of the polaroid A. If the intensity of the transmitted light from the polaroid A is I_0, then find out the

intensity of the polarised light transmitted from the polaroid B. For which angle θ the intensity of the transmitted light will be maximum?

Solution:

Intensity of Polarized Light through Crossed Polaroids:

Let's consider the configuration where polaroids A and B are crossed, meaning their polarizing axes are at 90° to each other. A third polaroid C is inserted between them, with its polarizing axis making an angle θ with the polarizing axis of polaroid A. The intensity of light after passing through polaroid A is I_0.

1. **Intensity of light after passing through polaroid A:** The intensity of light after passing through polaroid A will be:

$$I_1 = I_0 \cos^2\theta,$$

where θ is the angle between the polarizing axis of A and C.

2. **Intensity of light after passing through polaroid B:** The intensity of light transmitted through polaroid B will depend on the angle between the polarizing axis of C and B. Let this angle be θ'. The intensity of the transmitted light from B is given by:

$$I_2 = I_1 \cos^2\theta' = I_0 \cos^2\theta \cos^2\theta'.$$

Since polaroids A and B are crossed, $\theta' = 90^\circ - \theta$. Thus, we have:

$$I_2 = I_0 \cos^2\theta \sin^2\theta.$$

3. **Maximum Intensity:** To find the angle for which the intensity of the transmitted light is maximum, we differentiate I_2 with respect to θ and set it equal to zero:

$$\frac{dI_2}{d\theta} = I_0\,(2\cos\theta\sin\theta \cdot \sin\theta \cdot \cos\theta) = 0.$$

The solution to this is:

$$\theta = 45^\circ.$$

Hence, the intensity of the transmitted light will be maximum when the angle θ between the polarizing axes of A and C is $45°$.

> Quick Tip
>
> When polaroids are crossed, the intensity of transmitted light is maximized when the polarizing axis of the middle polaroid is at $45°$ to the axes of the first and last polaroids.

(b) What is the principle of a moving coil galvanometer? Draw its neat labelled diagram. How is the sensitivity of the galvanometer increased?

Solution:

Principle of a Moving Coil Galvanometer:

A moving coil galvanometer is an instrument used for detecting and measuring small electrical currents. It operates on the principle that when a current-carrying conductor is placed in a magnetic field, it experiences a force. This force is given by:

$$F = BIL,$$

where:

- B is the magnetic field strength,
- I is the current passing through the conductor,
- L is the length of the conductor in the magnetic field.

In a moving coil galvanometer, a coil of wire is placed in a uniform magnetic field. When a current flows through the coil, it experiences a torque, causing the coil to rotate. The deflection of the coil is proportional to the current flowing through it. A spring is used to restore the coil to its original position, and a scale is used to measure the deflection.

Increasing Sensitivity:

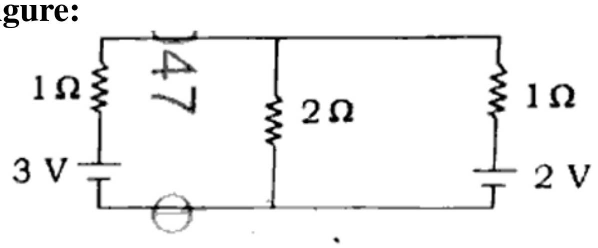
The sensitivity of a moving coil galvanometer depends on factors such as:

1. **Number of turns in the coil:** Increasing the number of turns in the coil increases the torque for a given current, which increases the sensitivity.

2. **Area of the coil:** Increasing the area of the coil also increases the torque, thus improving the sensitivity.
3. **Strength of the magnetic field:** A stronger magnetic field increases the force acting on the coil, thus increasing the sensitivity.
4. **Spring constant:** A lower spring constant makes the galvanometer more sensitive, as it requires less force to produce a given deflection.
By optimizing these factors, the sensitivity of the galvanometer can be increased, allowing it to measure smaller currents more accurately.

> Quick Tip
>
> To increase the sensitivity of a galvanometer, increase the number of turns in the coil, use a larger coil area, and use a stronger magnetic field. A lower spring constant also improves sensitivity.

(c) What is the first law of Kirchhoff of the electrical circuit? Find out the potential difference between the ends of 2 Ω resistor with the help of Kirchhoff's law. See the figure:



Solution:
Kirchhoff's First Law (or Junction Law) states that the algebraic sum of currents entering a junction is equal to the algebraic sum of currents leaving the junction. Mathematically, this can be written as:

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$

In the given circuit, we have two batteries and resistors. The resistances and voltages are given as: - $R_1 = 1\,\Omega$, $R_2 = 2\,\Omega$, $R_3 = 1\,\Omega$, - $V_1 = 3\,\text{V}$, $V_2 = 2\,\text{V}$.

We need to find the potential difference across the 2 Ω resistor R_2. To solve this using Kirchhoff's law, we first assign current directions (say I_1, I_2, and I_3 for different parts of the circuit) and write the equations for the loops in the circuit.
Step 1: Apply Kirchhoff's Voltage Law (KVL) to Loop 1 (containing V_1, R_1, and R_2):

$$-V_1 + I_1R_1 + I_2R_2 = 0$$

Substitute the values:

$$-3 + I_1 \times 1 + I_2 \times 2 = 0 \quad \text{(Equation 1)}$$

Step 2: Apply Kirchhoff's Voltage Law (KVL) to Loop 2 (containing V_2, R_2, and R_3):

$$-V_2 + I_2R_2 + I_3R_3 = 0$$

Substitute the values:

$$-2 + I_2 \times 2 + I_3 \times 1 = 0 \quad \text{(Equation 2)}$$

Step 3: Apply Kirchhoff's Current Law (KCL) at the junction (where I_1, I_2, and I_3 meet):

$$I_1 = I_2 + I_3 \quad \text{(Equation 3)}$$

Step 4: Solve the system of equations. From Equations 1, 2, and 3, solve for the currents I_1, I_2, and I_3. The potential difference across the $2\,\Omega$ resistor is $V = I_2 \times R_2$.
Calculation:

$$I_2 = \frac{V_2 - I_3R_3}{R_2} = \frac{2 - I_3 \times 1}{2} = 1 - \frac{I_3}{2}$$

Using the junction equation and solving for currents, we find the potential difference across R_2.

Quick Tip
Kirchhoff's laws help to solve complex circuits systematically by providing relationships between currents and voltages in different parts of the circuit.

(d) The area of a plane coil 1000 turns is 500 cm^2 and it is held perpendicular to a uniform magnetic field of 4×10^{-4} weber/m^2. It is turned through 180° angle in 0.1 second. Calculate the average induced e.m.f. produced in the coil.

Solution:

The average induced e.m.f. in a coil can be calculated using Faraday's law of electromagnetic induction, which states that the induced e.m.f. is equal to the rate of change of magnetic flux through the coil. The formula for induced e.m.f. is:

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

Where: - N is the number of turns of the coil, - $\Delta\Phi$ is the change in magnetic flux, - Δt is the time interval.

The magnetic flux Φ is given by:

$$\Phi = B \times A \times \cos\theta$$

Where: - B is the magnetic field strength, - A is the area of the coil, - θ is the angle between the normal to the plane of the coil and the magnetic field.

Step 1: Calculate the initial and final magnetic flux.

Initially, the coil is perpendicular to the magnetic field, so $\theta = 0^\circ$, and $\cos 0^\circ = 1$. The initial magnetic flux is:

$$\Phi_{\text{initial}} = B \times A \times 1 = (4 \times 10^{-4}) \times (500 \times 10^{-4}) = 2 \times 10^{-2}\,\text{Wb}$$

Finally, after the coil is turned through 180°, $\theta = 180^\circ$, and $\cos 180^\circ = -1$. The final magnetic flux is:

$$\Phi_{\text{final}} = B \times A \times (-1) = -(2 \times 10^{-2}) = -2 \times 10^{-2}\,\text{Wb}$$

Step 2: Calculate the change in magnetic flux.

The change in magnetic flux is:

$$\Delta\Phi = \Phi_{\text{final}} - \Phi_{\text{initial}} = -2 \times 10^{-2} - 2 \times 10^{-2} = -4 \times 10^{-2}\,\text{Wb}$$

Step 3: Calculate the induced e.m.f.

The time interval $\Delta t = 0.1\,\text{s}$, and the number of turns $N = 1000$. Now, using Faraday's law:

$$\varepsilon = -1000 \times \frac{-4 \times 10^{-2}}{0.1} = 400\,\text{V}$$

Thus, the average induced e.m.f. is $400\,\text{V}$.

Quick Tip

The induced e.m.f. depends on the rate of change of the magnetic flux. A larger change in flux or faster rotation results in a higher induced e.m.f.

(e) What is meant by displacement current? The amplitude of electric field of an electromagnetic wave is $E_0 = 120\,$N/C and frequency is $\nu = 50\,$MHz. Find out:

i) Amplitude of the magnetic field B_0

ii) Wavelength λ of the electromagnetic wave.

Solution:

Displacement Current:

Displacement current is a term introduced by James Clerk Maxwell to extend Ampère's law to situations involving time-varying electric fields. The displacement current density is given by:

$$J_D = \varepsilon_0 \frac{\partial E}{\partial t},$$

where:

- J_D is the displacement current density,
- ε_0 is the permittivity of free space,
- $\frac{\partial E}{\partial t}$ is the rate of change of the electric field with respect to time.

The displacement current plays a crucial role in explaining how electric fields can generate magnetic fields in a vacuum or in materials with varying electric fields, forming the foundation of electromagnetic wave propagation.

i) Amplitude of the Magnetic Field B_0:

The electric field E_0 and the magnetic field B_0 in an electromagnetic wave are related by the speed of light c. The relationship between the electric and magnetic field amplitudes in an electromagnetic wave is:

$$E_0 = cB_0,$$

where:

- c is the speed of light in vacuum ($c = 3 \times 10^8$ m/s),
- B_0 is the amplitude of the magnetic field.

Rearranging the formula to solve for B_0:

$$B_0 = \frac{E_0}{c}.$$

Substituting the given values $E_0 = 120\,\text{N/C}$ and $c = 3 \times 10^8$ m/s:

$$B_0 = \frac{120}{3 \times 10^8} = 4 \times 10^{-7}\,\text{T}.$$

So, the amplitude of the magnetic field B_0 is $4 \times 10^{-7}\,\text{T}$.

ii) Wavelength λ of the Electromagnetic Wave:

The wavelength λ of an electromagnetic wave is related to its frequency ν by the equation:

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

where:

- c is the speed of light in vacuum (3×10^8 m/s),
- ν is the frequency of the wave.

Substituting the given value of frequency $\nu = 50\,\text{MHz} = 50 \times 10^6\,\text{Hz}$:

$$\lambda = \frac{3 \times 10^8}{50 \times 10^6} = 6\,\text{m}.$$

So, the wavelength λ of the electromagnetic wave is $6\,\text{m}$.

💡 Quick Tip

In an electromagnetic wave, the electric and magnetic field amplitudes are related by the speed of light, and the wavelength is inversely proportional to the frequency of the wave.

Q.5 (a) Mention the required conditions for the interference of light. In Young's double slit experiment, the intensity of light at a point on the screen is I, when path difference is λ by using monochromatic light of wavelength λ. Find the intensity of light at that point, where path difference is $\frac{\lambda}{4}$.

Solution:

Conditions for Interference:

The main conditions for the interference of light are as follows: 1. **Coherence:** The two light sources must be coherent, meaning they must have a constant phase relationship. 2. **Monochromatic light:** The light used should be monochromatic (of a single wavelength), as interference depends on the wavelength of the light. 3. **Same amplitude:** The amplitudes of the two interfering waves should be the same or nearly the same. 4. **Superposition principle:** The resultant intensity at any point is the sum of the individual intensities due to each wave at that point, following the principle of superposition.

Intensity of Light when Path Difference is $\frac{\lambda}{4}$:

In Young's double-slit experiment, the intensity of light at a point on the screen is given by the equation:

$$I = I_{\text{max}} \cos^2\left(\frac{\pi \Delta x}{\lambda}\right),$$

where: - I is the intensity at a given point,
- I_{max} is the maximum intensity,
- Δx is the path difference between the two waves,
- λ is the wavelength of the monochromatic light.

For path difference $\Delta x = \frac{\lambda}{4}$, we substitute into the equation:

$$I = I_{\max} \cos^2\left(\frac{\pi \cdot \frac{\lambda}{4}}{\lambda}\right) = I_{\max} \cos^2\left(\frac{\pi}{4}\right).$$

Since $\cos\left(\frac{\pi}{4}\right) = \frac{1}{\sqrt{2}}$, we have:

$$I = I_{\max}\left(\frac{1}{\sqrt{2}}\right)^2 = \frac{I_{\max}}{2}.$$

Thus, the intensity of light at a point where the path difference is $\frac{\lambda}{4}$ is half of the maximum intensity:

$$I = \frac{I_{\max}}{2}.$$

Quick Tip
In interference, the intensity depends on the phase difference between the two waves. When the path difference is λ, the waves are in phase and constructive interference occurs, resulting in maximum intensity. For a path difference of $\frac{\lambda}{4}$, the waves are out of phase by $90°$, leading to partial destructive interference.

(b) What is meant by resonant circuit? Write down the required condition for the L-C-R series resonant circuit and expression for the frequency in resonant condition.

Solution:

Resonant Circuit:

A resonant circuit, also called a tuned circuit, is an electrical circuit that resonates at a particular frequency, called the resonant frequency. In such a circuit, the inductive reactance (X_L) and capacitive reactance (X_C) are equal and cancel each other out, resulting in a minimum impedance.

Condition for Resonance in L-C-R Series Circuit:

In a series L-C-R circuit, resonance occurs when the inductive reactance and capacitive reactance are equal in magnitude but opposite in phase. The condition for resonance is:

$$X_L = X_C,$$

where: - $X_L = \omega L$ is the inductive reactance,

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

- ω is the angular frequency ($\omega = 2\pi f$),

- L is the inductance,

- C is the capacitance.

At resonance, $X_L = X_C$, so:

$$\omega L = \frac{1}{\omega C}.$$

Solving for the angular frequency ω at resonance:

$$\omega^2 = \frac{1}{LC},$$

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

The resonant frequency f_0 is then:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}.$$

Quick Tip

In an L-C-R series circuit, resonance occurs when the reactances of the inductor and capacitor cancel each other out, resulting in minimum impedance. At this point, the circuit can oscillate freely at the resonant frequency.

OR

In the given figure, LCR circuit is shown. Voltage of the alternating current source is $V = 100\sin(500t)$ volt. Calculate for the circuit:

Solution:

(i) Total impedance

The total impedance Z of an L-C-R series circuit is given by:

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

where: - $R = 40\,\Omega$ is the resistance,

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

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

Given: - $L = 0.16\,\text{H}$, - $C = 40\,\mu\text{F} = 40 \times 10^{-6}\,\text{F}$, - $\omega = 500\,\text{rad/s}$ (since the frequency $f = \frac{500}{2\pi}$).

First, calculate X_L and X_C:

$$X_L = \omega L = 500 \times 0.16 = 80\,\Omega,$$

$$X_C = \frac{1}{\omega C} = \frac{1}{500 \times 40 \times 10^{-6}} = 50\,\Omega.$$

Now, substitute these values into the impedance formula:

$$Z = \sqrt{40^2 + (80 - 50)^2} = \sqrt{1600 + 900} = \sqrt{2500} = 50\,\Omega.$$

So, the total impedance is $Z = 50\,\Omega$.

(ii) Power Factor:

The power factor (PF) in a series L-C-R circuit is given by:

$$\text{PF} = \cos\phi = \frac{R}{Z},$$

where: - $R = 40\,\Omega$, - $Z = 50\,\Omega$.

So, the power factor is:

$$\text{PF} = \frac{40}{50} = 0.8.$$

(iii) Peak Value of Current:

The peak current I_0 in the circuit is given by:

$$I_0 = \frac{V_0}{Z},$$

where: - $V_0 = 100\,\text{V}$ is the peak voltage,

- $Z = 50\,\Omega$ is the total impedance.

So, the peak value of the current is:

$$I_0 = \frac{100}{50} = 2\,\text{A}.$$

Quick Tip

In an L-C-R circuit, the impedance depends on the resistance, inductive reactance, and capacitive reactance. The power factor is the cosine of the phase angle, and the peak current is determined by the peak voltage and total impedance.

(c) Draw a graph between de Broglie wavelength (λ) and momentum (p) of a moving particle. A proton and an α-particle are accelerated by the same potential. Compute the ratio of their de Broglie wavelengths.

Solution:

The de Broglie wavelength (λ) of a particle is related to its momentum (p) by the equation:

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

Where:

- λ is the de Broglie wavelength,
- h is Planck's constant (6.626×10^{-34} J $\cdot$ s),
- p is the momentum of the particle.

Since momentum is given by $p = mv$, where m is the mass and v is the velocity of the particle, we can write:

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

Now, consider a proton and an α-particle (helium nucleus) accelerated by the same potential difference. The kinetic energy K acquired by a particle when accelerated by a potential V is given by:

$$K = \frac{1}{2}mv^2 = qV$$

Where q is the charge of the particle and V is the potential. For a proton, $q = e$ and for an α-particle, $q = 2e$. From this, we can find the velocity of each particle and subsequently the momentum.

For the proton, the velocity v_p is:

$$\frac{1}{2}m_p v_p^2 = eV \quad \Rightarrow \quad v_p = \sqrt{\frac{2eV}{m_p}}$$

For the α-particle, the velocity v_α is:

$$\frac{1}{2}m_\alpha v_\alpha^2 = 2eV \quad \Rightarrow \quad v_\alpha = \sqrt{\frac{4eV}{m_\alpha}}$$

Now, the de Broglie wavelength for the proton (λ_p) and the α-particle (λ_α) are:

$$\lambda_p = \frac{h}{m_p v_p} = \frac{h}{m_p\sqrt{\frac{2eV}{m_p}}} = \frac{h}{\sqrt{2m_p eV}}$$

$$\lambda_\alpha = \frac{h}{m_\alpha v_\alpha} = \frac{h}{m_\alpha\sqrt{\frac{4eV}{m_\alpha}}} = \frac{h}{\sqrt{4m_\alpha eV}}$$

Finally, the ratio of their de Broglie wavelengths is:

$$\frac{\lambda_p}{\lambda_\alpha} = \frac{\frac{h}{\sqrt{2m_p eV}}}{\frac{h}{\sqrt{4m_\alpha eV}}} = \sqrt{\frac{4m_\alpha}{2m_p}} = \sqrt{2\frac{m_\alpha}{m_p}}$$

Since the mass of a proton m_p is approximately 1836 times the mass of an electron, and the mass of an α-particle $m_\alpha = 4m_p$, we get:

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{2 \times \frac{4m_p}{m_p}} = \sqrt{8} \approx 2.83$$

Thus, the ratio of the de Broglie wavelengths of the proton and α-particle is approximately 2.83.

Quick Tip

The de Broglie wavelength of a particle is inversely proportional to its momentum. The ratio of de Broglie wavelengths for two particles can be calculated by finding the ratio of their momenta, considering their masses and charges.

(d) Two cells are of emf's E_1 and E_2 and their internal resistances are r_1 and r_2 respectively. They are joined in parallel to each other. Obtain the formula for the equivalent emf of this combination of cells.

Solution:

When two cells with different electromotive forces (emfs) and internal resistances are connected in parallel, the equivalent emf E_{eq} and the equivalent internal resistance r_{eq} can be found using the following approach:

Step 1: Calculate the equivalent internal resistance.

The two internal resistances r_1 and r_2 are in parallel, so the total internal resistance r_{eq} is given by:

$$\frac{1}{r_{\text{eq}}} = \frac{1}{r_1} + \frac{1}{r_2}$$

Therefore, the equivalent internal resistance is:

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

Step 2: Calculate the equivalent emf.

The equivalent emf of two cells in parallel is given by the formula:

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

This formula takes into account both the emfs and the internal resistances of the two cells. The equivalent emf is a weighted average of the two emfs, where the internal resistances act as the weights.

Thus, the formula for the equivalent emf of the combination of cells is:

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

Quick Tip

When cells are connected in parallel, the equivalent emf is a weighted average of the individual emfs, where the internal resistances of the cells act as weights.

(e) Write down the formula for the force in vector form, acting on a moving charged particle in a uniform electric and magnetic fields. Obtain the formula for the radius of the path of the particle entering perpendicular to the magnetic field only. What is the law for the direction of force acting on the particle?

Solution:

The force acting on a charged particle moving in the presence of both electric and magnetic fields is given by the Lorentz force law, which is:

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

Where: - $\mathbf{F}$ is the total force on the particle.
- q is the charge of the particle.
- $\mathbf{E}$ is the electric field.
- $\mathbf{v}$ is the velocity of the particle.
- $\mathbf{B}$ is the magnetic field.
- $\mathbf{v} \times \mathbf{B}$ represents the cross product of the velocity and the magnetic field vectors, which gives the direction of the magnetic force.

This formula accounts for both the electric force ($q\mathbf{E}$) and the magnetic force ($q\mathbf{v} \times \mathbf{B}$).

Now, let's focus on the case where the particle is moving perpendicular to the magnetic field, and the electric field is neglected (i.e., $\mathbf{E} = 0$):

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

Radius of the Path:

When a charged particle moves perpendicular to a magnetic field, it experiences a magnetic force that causes it to move in a circular path. The force acts as a centripetal force, and the radius of the path can be derived using the equation for the centripetal force:

$$F_{\text{magnetic}} = F_{\text{centripetal}}$$

The magnetic force is:

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

Where: - m is the mass of the particle,
- r is the radius of the circular path.
Solving for the radius r, we get:

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

Thus, the radius of the circular path of the particle is directly proportional to its mass and velocity, and inversely proportional to the charge of the particle and the magnetic field strength.

Direction of the Force:

The direction of the magnetic force is given by the right-hand rule: - Point your fingers in the direction of the velocity $\mathbf{v}$. - Curl your fingers towards the direction of the magnetic field $\mathbf{B}$. - Your thumb will point in the direction of the force $\mathbf{F}$ acting on a positive charge. For a negative charge, the force will be in the opposite direction.

Quick Tip

When dealing with the force on a charged particle in a magnetic field, always remember the right-hand rule for the direction of the force. The formula for the radius of the path is $r = \frac{mv}{qB}$, which applies when the velocity is perpendicular to the magnetic field.

Section - E

Q.6 (a) Derive the formula for the intensity of electric field on the bisector (equatorial line) of an electric dipole.

Solution:

Intensity of Electric Field on the Bisector of an Electric Dipole:

Consider an electric dipole consisting of two charges $+q$ and $-q$, separated by a distance $2a$. The dipole is placed along the x-axis, with the charges located at $x = +a$ and $x = -a$.

The point where we need to calculate the electric field lies on the bisector (the equatorial line) of the dipole, which is at a distance r from the center of the dipole. The angle between the line joining the charges and the point on the bisector is $90°$.

To calculate the electric field at this point:

1. Electric field due to the positive charge $+q$: The electric field due to a point charge is given by:

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}.$$

For the positive charge at a distance r from the point, the electric field is directed radially away from the charge. Since the point lies on the bisector, the field due to the positive charge will have a component along the direction of the bisector.

2. Electric field due to the negative charge $-q$: Similarly, the electric field due to the negative charge at the same distance r will also have a component along the bisector, but it will be directed towards the negative charge.

3. Net Electric Field on the Bisector: Since both electric fields are of equal magnitude but opposite directions, they add up along the bisector. The net electric field is:

$$E_{\text{net}} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3},$$

where $p = q \cdot 2a$ is the dipole moment of the system.

Thus, the intensity of the electric field on the bisector (equatorial line) of an electric dipole is:

$$E_{\text{net}} = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}.$$

💡 Quick Tip

For an electric dipole, the electric field on the equatorial line is inversely proportional to the cube of the distance from the center of the dipole, and it is directed along the bisector.

OR

Derive the formula for the capacitance of a parallel plate capacitor, when a dielectric slab is partially filled in between its plates.

Solution:

Capacitance of a Parallel Plate Capacitor with Partial Dielectric Slab:

Consider a parallel plate capacitor with plate area A and separation d between the plates. Let the capacitor be partially filled with a dielectric material of dielectric constant ε_r and thickness t. The remaining gap is filled with air.

The total capacitance can be considered as the combination of two capacitors in series: 1. The capacitor with dielectric slab: Capacitance C_1, 2. The capacitor with air gap: Capacitance C_2.

1. Capacitance with dielectric slab: The capacitance of the part filled with the dielectric is given by:

$$C_1 = \frac{\varepsilon_r \varepsilon_0 A}{t}.$$

2. Capacitance with air gap: The capacitance of the part filled with air is given by:

$$C_2 = \frac{\varepsilon_0 A}{d - t}.$$

3. Total Capacitance (Series Combination): Since the two capacitors are in series, the total capacitance C is given by:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}.$$

Substituting the expressions for C_1 and C_2:

$$\frac{1}{C} = \frac{t}{\varepsilon_r \varepsilon_0 A} + \frac{d-t}{\varepsilon_0 A}.$$

Simplifying the expression:

$$\frac{1}{C} = \frac{d}{\varepsilon_0 A}.$$

Thus, the total capacitance is:

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

So, the capacitance of a parallel plate capacitor with a partial dielectric filling is the same as that of an empty capacitor, but with the dielectric slab affecting the effective area.

Quick Tip

When a dielectric is partially filled in a capacitor, treat the two sections (dielectric and air) as separate capacitors in series. The total capacitance is calculated using the series combination formula.

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7 Explain the working of a forward biased ($p-n$) junction diode by making circuit diagram and by drawing its $V-I$ characteristic graph. Define its dynamic resistance.

Solution:

A p-n junction diode is formed by joining a p-type semiconductor and an n-type semiconductor. When the diode is forward biased (i.e., the p-side is connected to the positive terminal of the battery and the n-side to the negative terminal), the majority charge carriers (holes from the p-side and electrons from the n-side) move towards the junction, reducing the width of the depletion region. As the applied voltage increases, the current increases rapidly after a threshold voltage (called the forward voltage).

Circuit Diagram:

In a forward biased condition, the circuit diagram is as shown below:

(Diagram with p-n junction diode, load resistance R_L, and the power supply)

The diode conducts only when the voltage exceeds a certain threshold (typically 0.7V for a silicon diode).

$V - I$ Characteristic Graph:

The $V - I$ characteristic of a p-n junction diode shows the relationship between the voltage across the diode and the current through it. The graph has the following features:

- For small forward voltages (less than 0.7V for silicon diodes), the current is almost zero (the diode does not conduct). - Once the forward voltage exceeds 0.7V, the current rises exponentially. - In reverse bias, the current is negligible until the breakdown voltage is reached, after which the current increases sharply.

Dynamic Resistance of the Diode:

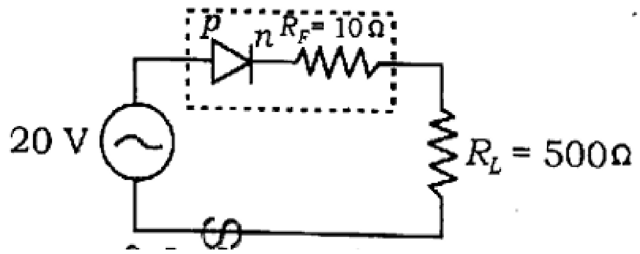
The dynamic resistance r_d of the diode in the forward biased condition is defined as the slope of the $V - I$ curve at any given point. It is given by:

$$r_d = \frac{dV}{dI}$$

At high currents, the dynamic resistance is very small (almost zero), as the diode behaves like a short circuit.

> Quick Tip
>
> For a silicon diode, the threshold voltage is typically around 0.7 V. The diode's dynamic resistance decreases as the current increases in forward bias.

OR An a.c. voltage of peak value 20 V is connected in series with a silicon diode and a load resistance of 500 Ω. The forward resistance of the diode is 10 Ω and the resistive voltage is 0.7 V. Find the peak current through the diode and peak voltage across the load.



Solution:

Given: - Peak voltage of the a.c. source, $V_{\text{peak}} = 20\,\text{V}$ - Load resistance, $R_L = 500\,\Omega$ - Forward resistance of the diode, $R_f = 10\,\Omega$ - Resistive voltage across the diode, $V_d = 0.7\,\text{V}$

Step 1: Calculate the total resistance in the circuit.

The total resistance in the circuit is the sum of the forward resistance of the diode and the load resistance:

$$R_{\text{total}} = R_L + R_f = 500\,\Omega + 10\,\Omega = 510\,\Omega$$

Step 2: Calculate the peak current through the diode.

The peak current through the diode can be calculated using Ohm's law:

$$I_{\text{peak}} = \frac{V_{\text{peak}} - V_d}{R_{\text{total}}}$$

Substituting the given values:

$$I_{\text{peak}} = \frac{20\,\text{V} - 0.7\,\text{V}}{510\,\Omega} = \frac{19.3\,\text{V}}{510\,\Omega} \approx 0.0379\,\text{A}$$

Thus, the peak current through the diode is approximately $0.0379\,\text{A}$.

Step 3: Calculate the peak voltage across the load.

The peak voltage across the load can be calculated using Ohm's law:

$$V_{\text{L peak}} = I_{\text{peak}} \times R_L$$

Substituting the values:

$$V_{\text{L peak}} = 0.0379\,\text{A} \times 500\,\Omega \approx 18.95\,\text{V}$$

Thus, the peak voltage across the load is approximately $18.95\,\text{V}$.

Quick Tip

For an a.c. circuit with a diode, subtract the resistive voltage across the diode from the peak supply voltage to find the voltage across the load. Then, apply Ohm's law to calculate the current and voltage across the load.

Q.8 What is meant by mass-defect? In a nuclear fission reaction, find out the value of the fission energy Q.

Solution:

Mass defect in a nuclear reaction refers to the difference in mass between the sum of the masses of the individual nucleons (protons and neutrons) and the mass of the entire nucleus. This difference in mass is converted into binding energy that holds the nucleus together, as per Einstein's equation $E = mc^2$.

For the given nuclear fission reaction:

$$^{235}_{92}U +^{1}_{0} n \rightarrow^{140}_{54} Xe +^{94}_{38} Sr + 2^{1}_{0}n + Q$$

We need to calculate the fission energy Q, which is given by the mass defect of the entire reaction. The formula for Q is:

$$Q = [(\text{Mass of Reactants}) - (\text{Mass of Products})] \times c^2$$

Given:

- Mass of $^{235}_{92}U = 235.0439\,\text{amu}$
- Mass of $^{140}_{54}Xe = 139.9054\,\text{amu}$
- Mass of $^{94}_{38}Sr = 93.9063\,\text{amu}$
- Mass of $^{1}_{0}n = 1.00867\,\text{amu}$
- $1\,\text{amu} = 931\,\text{MeV}/c^2$

Step 1: Find the mass of reactants and products

- Mass of reactants: $235.0439 + 1.00867 = 236.05257\,\text{amu}$
- Mass of products: $139.9054 + 93.9063 + 2(1.00867) = 235.829\,\text{amu}$

Step 2: Calculate the mass defect

Mass defect $\Delta m = 236.05257 - 235.829 = 0.22357\,\text{amu}$

Step 3: Convert mass defect to energy

$$Q = 0.22357 \times 931\,\text{MeV} = 208.9\,\text{MeV}$$

Thus, the fission energy Q is approximately 208.9 MeV.

Quick Tip

The mass defect represents the difference between the mass of the individual particles and the mass of the nucleus. This difference is the energy released during nuclear reactions and is given by $E = \Delta m \cdot c^2$.

OR

Draw energy level diagram for hydrogen atom. Show the transitions of the first line of Lyman series and second line of Balmer series. Find out the ratio of their wavelengths.

Solution:

In the hydrogen atom, the energy levels are given by the formula:

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

Where: - E_n is the energy of the nth level, - n is the principal quantum number, - 13.6 eV is the Rydberg energy for hydrogen.

1. Energy Level Diagram for Hydrogen:

The energy levels in the hydrogen atom are shown in the diagram below:

In this diagram: - The energy of the electron decreases as it moves closer to the nucleus.

- The ground state corresponds to $n = 1$, and higher levels correspond to $n = 2, 3, 4, \ldots$.

2. Lyman Series Transitions:

The Lyman series corresponds to transitions where the final state is $n = 1$ (the ground state). The first line of the Lyman series occurs when the electron transitions from $n = 2$ to $n = 1$. The energy difference between these levels is:

$$\Delta E_1 = E_2 - E_1 = \left(-\frac{13.6}{2^2}\right) - \left(-\frac{13.6}{1^2}\right) = -3.4\,\text{eV} + 13.6\,\text{eV} = 10.2\,\text{eV}$$

The wavelength λ_1 of this transition is given by the formula:

$$\lambda_1 = \frac{hc}{\Delta E_1}$$

Substituting the values ($h = 6.626 \times 10^{-34}\,\text{J}\cdot\text{s}$, $c = 3 \times 10^8\,\text{m/s}$, and $\Delta E_1 = 10.2\,\text{eV}$):

$$\lambda_1 = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{10.2 \times 1.602 \times 10^{-19}} \approx 121.6\,\text{nm}$$

3. Balmer Series Transitions:

The Balmer series corresponds to transitions where the final state is $n = 2$. The second line of the Balmer series occurs when the electron transitions from $n = 3$ to $n = 2$. The energy difference is:

$$\Delta E_2 = E_3 - E_2 = \left(-\frac{13.6}{3^2}\right) - \left(-\frac{13.6}{2^2}\right) = -1.511\,\text{eV} + 3.4\,\text{eV} = 1.889\,\text{eV}$$

The wavelength λ_2 of this transition is:

$$\lambda_2 = \frac{hc}{\Delta E_2} = \frac{6.626 \times 10^{-34} \times 3 \times 10^8}{1.889 \times 1.602 \times 10^{-19}} \approx 656.3\,\text{nm}$$

4. Ratio of the Wavelengths:

The ratio of the wavelengths is:

$$\frac{\lambda_1}{\lambda_2} = \frac{121.6\,\text{nm}}{656.3\,\text{nm}} \approx 0.185$$

Thus, the ratio of the wavelengths of the first line of the Lyman series and the second line of the Balmer series is approximately 0.185.

> Quick Tip
>
> For hydrogen atom transitions, remember the energy of the transition is given by $\Delta E = E_{\text{final}} - E_{\text{initial}}$, and the wavelength is related to the energy by $\lambda = \frac{hc}{\Delta E}$.

Q.9 Draw a labelled ray diagram of an astronomical telescope and derive the formula of its magnifying power.

Solution:

An astronomical telescope is designed to view distant objects in the sky, such as stars and planets, at a magnified scale. It consists of two lenses: the objective lens and the eyepiece.

- The objective lens (O) has a large focal length and is placed at a distance from the object. It forms a real, inverted image of the object at its focal plane.

- The eyepiece (E) is used to magnify the image formed by the objective lens. It is placed close to the focal plane of the objective lens and is used as a magnifying glass.
In the diagram: - O is the objective lens.
- E is the eyepiece.
- F_o and F_e are the focal points of the objective and eyepiece, respectively.
- The image formed by the objective lens is at the focal plane F_o, and it is magnified by the eyepiece.

The magnifying power M of the telescope is the ratio of the angular size of the image seen through the telescope (θ') to the angular size of the object when viewed with the unaided eye (θ).
The formula for magnifying power of the telescope is:

$$M = \frac{\theta'}{\theta} = \frac{f_o}{f_e}$$

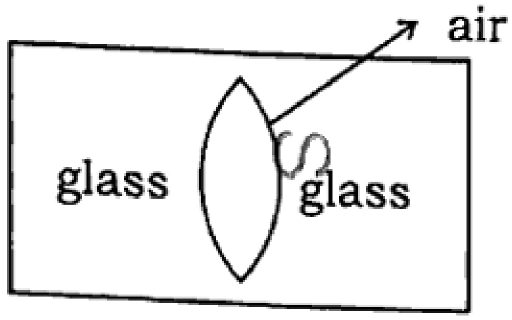
Where: - f_o is the focal length of the objective lens,
- f_e is the focal length of the eyepiece.
The magnifying power is directly proportional to the focal length of the objective lens and inversely proportional to the focal length of the eyepiece.

Quick Tip

For an astronomical telescope, the longer the focal length of the objective lens and the shorter the focal length of the eyepiece, the greater the magnifying power.

OR

An air bi-convex lens of 10 cm radius of curvature is placed in a cylinder of glass ($n = \frac{3}{2}$), as shown in the figure. Find the focal length and nature of the lens. If a liquid of refractive index $n' = 2$ is filled in the lens, then what will be the power and nature of the lens?



Solution:

A bi-convex lens is a type of lens in which both surfaces are convex. The focal length of a lens is determined by the lensmaker's formula:

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

Where: - f is the focal length of the lens,

- n is the refractive index of the material of the lens,

- R_1 and R_2 are the radii of curvature of the two surfaces of the lens.

For a bi-convex lens, $R_1 = +10$ cm (convex surface) and $R_2 = -10$ cm (concave surface). The refractive index of the glass is $n = \frac{3}{2}$.

Substituting these values into the lensmaker's formula:

$$\frac{1}{f} = \left(\frac{3}{2} - 1\right)\left(\frac{1}{10} - \frac{1}{-10}\right)$$
$$\frac{1}{f} = \frac{1}{2} \times \left(\frac{2}{10}\right)$$
$$\frac{1}{f} = \frac{1}{10}$$

Thus, the focal length of the lens is:

$$f = 10 \text{ cm}$$

The lens is a converging lens because it is bi-convex.

Now, when the lens is filled with a liquid of refractive index $n' = 2$, we use the modified lensmaker's formula:

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

Where $n' = 2$ is the refractive index of the liquid. Substituting the values into the formula:

$$\frac{1}{f'} = (2-1)\left(\frac{1}{10} - \frac{1}{-10}\right)$$
$$\frac{1}{f'} = 1 \times \left(\frac{2}{10}\right)$$
$$\frac{1}{f'} = \frac{2}{10}$$

Thus, the new focal length of the lens when filled with liquid is:

$$f' = 5 \text{ cm}$$

The nature of the lens remains converging, but its focal length decreases due to the increased refractive index.

The power P of the lens is given by:

$$P = \frac{1}{f}$$

The power in air is:

$$P = \frac{1}{10} = 0.1 \text{ diopters}$$

The power in the liquid is:

$$P' = \frac{1}{5} = 0.2 \text{ diopters}$$

Quick Tip

When the lens is filled with a liquid, its focal length decreases, and the power increases. A higher refractive index leads to a stronger lens.
